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LICHENS AND MONUMENTS

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LICHEN-INDUCED BIODETERIORATION OF ITALIAN MONUMENTS, FRESCOES AND OTHER ARCHAEOLOGICAL MATERIALS

M.R.D. SEAWARD and C. GIACOBINI

Keywords: Archaeology, Biodeterioration, Frescoes, Italy, Lichens, Monuments, Ostia, Rome, Terracotta.

Abstract: An appraisal is made of the part played by lichens in the deterioration of stonework. Stone- and art- work in exposed and partially enclosed environments of Central Italy were examined in detail to identify those substrata most vulnerable to lichen attack. Assessment of relationships between particular species and the physical and chemical nature of their substrata was carried out in order to determine the relative importance of lichens in biodeterioration processes obtaining in specific circumstances, and to establish those species responsible for disfigurement and those causing actual destruction. Particular attention is paid to recent environmental changes conducive to increasing detrimental invasion of terracotta, mortar and painted plaster, and reference is made to examples of building materials, statuary and other ornamental carvings, terracotta pots and frescoes, both those *in situ* at Ostia Antica, Rome and Caprarola (Viterbo) and those relocated in open-air museums, etc.

Introduction

Those concerned with the preservation of monuments view the encroachment of lichens as a disfiguring threat, obscuring inscriptions and fine detail and often causing actual physical deterioration of the stonework itself. Since damage can be brought about by a multitude of both physical and chemical processes, exacerbated in urban environments, as well as through biodeterioration, it is essential to determine that damage to any particular monument is indeed attributable to lichen action, especially since cleaning techniques may well accelerate deterioration.

These problems are particularly evident in those countries such as Italy where ancient cities are exceptionally rich in fine historical monuments of international importance. The problems are under-researched, due to the lack of interdisciplinary co-operation, and much of the published work is of a largely empirical nature. Collaborative research between the Department of Microbiology of the Institute for Restoration in Rome and the School of Environmental Science at Bradford University has been undertaken since 1982 (e.g. Giacobini *et al.* 1986), but not until four years later was the opportunity afforded for the respective researchers to actually work together on site.

The role of lichens in the biodeterioration of stonework

Undoubtedly some lichen species do contribute to the deterioration of a wide range of building materials. Biodeterioration of stonework can be the result of either physical or chemical processes. Modern electron microscopy and chemical tecniques have made it possible to recognise that lichens are implicated in both these processes. In the past, attention was drawn to the possible effect of dissolved carbon dioxide, derived from lichen respiration, attacking the substratum to produce pits and channels for easier penetration of hyphae, with attendant loosening of mineral particles and their incorporation into lichen tissue. Such effects, although important on a geological time-scale, have so far been considered to be minimal in terms of the life of ancient monuments. However, it would appear from observations made during the course of this study that many lichen species create microclimatic effects at the thallus/substratum interface, particularly in terms of water retention, which undoubtedly lead to mechanical damage to stonework on a short time-scale of ten, or even fewer, years. Various crustose and squamulose lichens are implicated, their aggressive behaviour no doubt promoted by particular man-made environmental conditions. Furthermore, forces generated by climatic wetting and drying of the lichen thallus cause it to expand and contract, which in turn mechanically disrupts the substratum. Taken in conjunction with the chemical breakdown of substrata by lichen acids, etc., it is clear that all these biogeophysical processes will assume greater importance.

Lichen acids have a relatively low solubility, but they are effective chelators, forming metal complexes with silicates, etc., derived from the substratum. X-ray powder diffraction and transmission electron microscopy have clearly demonstrated the presence of characteristic alteration products at the interface between rocks and various lichens. Experiments involving pure lichen acids or lichen fragments incubated with different types of rock have confirmed these observations. Many lichens known to contain calcium oxalate cause extensive corrosion of a range of rock substrata. Oxalic acid secreted by the mycobiont is extremely soluble in water and acts as a chelator of metal ions, and oxalates formed at the thallus/substratum interface are closely related to the chemical composition of the rock; thus, species growing on serpentinite, mainly composed of magnesium silicate, form magnesium oxalate dihydrate at the interface.

The report by Del Monte and Sabbioni (1987) of the occurrence of oxalates and lichen fragments in *scialbatura,* the patina of exposed marble monuments, etc., is of particular interest in this context and warrants further investigation, as do the findings of Krumbein and Schönborn-Krumbein (1987) regarding the role played by lichens in specific types of pitting of ancient stonework; however, the nature of the penetrations appears to be uncharacteristic of previously observed lichen action. It is possible that lichens have initiated a chain of reactions resulting in such deterioration, but the precise extent of their involvement, particularly in respect of the time-scale, needs clarification.

There is, therefore, strong reason to believe that lichen acids, oxalic acid and

other organic acids are all involved in the biodeterioration of stonework, etc., and that some mechanical processes may be interacting with these chemical processes (Jones & Wilson 1985).

Study sites

Detailed investigations were made at the following sites:
(1) Villa Madama, Rome - house, and gardens (statues, walls, pavements and sarcophagus).
(2) Tombe Latine, Rome - above-ground calcareous and siliceous stonework, and shaded subterranean walls.
(3) St. Stephen's Basilica, Rome - walls and fallen columns.
(4) Museo Nazionale Romano - outdoor monuments made of a variety of stonework, and terracotta pots.
(5) Palazzo Farnese, Caprarola - wall frescoes on ground and first floor cloisters facing onto inner courtyard, and garden monuments and walls.
(6) Ostia Antica - buildings, pavements and monuments in a variety of stonework, and *in situ* terracotta storage pots.

In addition, numerous other archaeological sites (e.g. Palatine and Capitoline Hills, Trajan's Forum), monuments, churches, etc. in Rome were visited, and their lichen floras noted (Seaward 1987). Comparisons were also made with the impoverished urban flora generally to be found in, and near to, Rome.

Results

(1) Villa Madama

The walls of the villa had scattered colonies of lichens, mainly *Dirina massiliensis* forma *sorediata*, but no species of particular interest; no problems of biodeterioration caused by lichen growth were noted. A neoclassical statue, near to the villa, was, however, clearly suffering from disfigurement, the main cause of which was due to algal growth creating, in particular, a dark rust-brown colouration of the face. Several lichens were detected as secondary colonizers to the alga, with small thalli of *D. massiliensis* forma *sorediata* becoming established in niches created, for example, by folds in the dress. Cleaning of such statuary should be undertaken before secondary colonizers have time to establish themselves. The plinth to this statue was more densely colonized by lichens, a few species, including *Leproplaca chrysodeta*, being suited to the drier, and sometimes shady crevices.

The lichen flora of the granitic columns in the garden walk contrasted sharply with that of the calcareous columns, the former being very poorly colonized, the only notable feature being a few thalli of the foliose *Parmelia glabratula* ssp. *fuliginosa*.

The calcareous columns, on the other hand, supported both foliose (e.g. *Physconia grisea*, *Physcia adscendens*, *Xanthoria parietina*) and crustose species

(mainly *Caloplaca* ssp. and *Verrucaria nigrescens*), several columns having large areas dominated by *Scoliciosporum umbrinum;* calcareous plinths to granitic columns had a similar flora.

An archaeologically important sarcophagus gave cause for concern: almost the entire surface of the three exposed faces was covered with lichens, mainly *Protoblastenia rupestris,* and algae, the only uncolonized areas being near to water spouts where the action of running water and presence of lead inhibited growth. The removal of this monument to a covered area is recommended.

Garden ornaments, such as seats, statues and their plinths, walls and pavements, being mainly of calcareous material, supported a diverse and often colourful lichen flora, the wall capstones in particular providing a pleasing mosaic of about 18 species, none of which appeared to be acting detrimentally. Unused areas of pavements were covered with lichens, occasionally *Collema crispum,* and the junction between the bowl of an urn and its base created a favourable habitat for *C. tenax* and secondary colonization by bryophytes.

(2) Tombe Latine

An avenue of interesting fragments of Roman buildings including short stretches of calcareous and siliceous (tufa) walls, together with isolated 'monoliths', supported rich lichen floras, often with a number of nitrophilous species (no doubt as a result of the application of agrochemicals in neighbouring gardens). Tufa walls were particularly colourful with at least 20 species, including *Caloplaca festiva, Candelariella coralliza, Lecanora muralis, Parmelia verruculifera, Xanthoria calcicola* and *X. parietina.* Walls constructed from a mixture of calcareous and non-calcareous stones, or siliceous stonework heavily pointed with cement, obviously created 'anomalous' mixed floras of such species as *Aspicilia calcarea* var. *reagens, Caloplaca aurantia, Lecidea fuscoatra, Lecanora campestris* and *Acarospora fuscata.* Wholly calcareous walls supported mainly crustose species, particularly *Lecanora pruinosa,* and occasionally *Physcia adscendens* and *Phaeophyscia orbicularis.* The shaded subterranean walls forming part of the Tomb of the Valeri were covered with *Lepraria incana,* scattered throughout with *Opegrapha mougeotii.*

(3) St Stephen's Basilica

Due to major reconstruction work, a sparse and species-poor calcareous flora, similar to that described at site 2 above, was encountered.

(4) Museo Nazionale Romano

A grassed area surrounded by cloistered museum buildings contained numerous archaeologically important monuments and artifacts constructed from a variety of materials. In interpreting the deterioration of these materials, the am-

bient urban climate (and associated atmospheric pollutants) should be taken into consideration, particularly since the latter dramatically affects the lichen flora: it was noted, for example, that several of the more toxi-tolerant species (poleophiles) with an aggressive behaviour were actively colonizing stonework, etc.

The funerary monument to the Fontei has been reconstructed from a variety of materials: the juxtaposition of calcareous and non-calcareous materials, particularly the use of heavy cement pointing over acidic stonework, has resulted in lichen colonization of the alkaline substrata in the first instance through the ability of the latter to buffer low pH pollutants derived from the atmosphere; from such colonization points, several species had spread onto more important areas of the monument. No ''damp-course'' was observed between the monument and the ground on which it stood, and there was strong evidence that fertilizers and/ or other chemicals had been used to treat the surrounding lawn in view of the presence of nitrophilous lichen species on the stonework, particularly near the base. The front of the monument had a relatively rich lichen flora, some species such as *Acarospora umbilicata* and *Lecidea fuscoatra* being obviously responsible for the deterioration on the right-hand side. The shaded back face also supported several species, including *Acarospora umbilicata, Buellia punctata* and *Scoliciosporum umbrinum.* Many of the disfigurement problems of this monument arose from an unsympathic use of materials for its reconstruction in the past. A similar case was observed in respect of a statue of a horse's head which had been mounted on a concrete neck, the latter providing the initial focus for unsightly lichen colonization.

The most dramatic and alarming case of lichen attack was observed in the case of several large terracotta pots scattered about the lawn. The rims and shoulders of these pots were lightly colonized by such innocuous species as *Lecanora dispersa* and *Candelariella vitellina,* with occasional thalli of *Acarospora umbilicata* and *Lecidea fuscoatra,* but here and there, thalli of *Lecanora muralis,* mainly 4-7 cm in diameter, probably representing less than 8, and no more than 15, years' growth, were causing demonstrable damage (Seaward 1988). A section through one of the thalli clearly reveals the results of such damage: a central blister, created by the crowding of apothecia, pulled away a fragment of the substratum two or more millimetres in thickness, over an area almost 12 cm^2. Re-examination of the terracotta pots in 1988 revealed several occurrences of identical surface blistering and subsequent flaking induced by *L. muralis,* thus substatiating the interpretation made two years earlier. *L. muralis* appears to be a highly successful lichen in urban environments into which it has spread dramatically, due in part to lack of competition from other species, over the past few years (Seaward 1982); a change in the nature of air pollution in Rome in that period may be a contributory factor to this aggressive behaviour.

(5) Palazzo Farnese

This beautiful mansion on a hillside, built by Vignola in 1547-49, features a

circular courtyard surrounded by cloisters on ground and first floor levels, the inner walls of which bear frescoes by Zuccari painted in the 1560s. The water-based paintwork has shown signs of biodeterioration in recent years; examination revealed that one lichen species, *Dirina massiliensis* forma *sorediata,* is responsible for the disfigurement. The latter gives great cause for concern, the attack being very pronounced in many places, showing the predilection of this lichen for the brown and yellow pigments, rather than the red pigment which probably contains a metal antagonistic to its growth. The distribution pattern of this lichen is not only dictated by the colour of the paintwork: when viewed at several paces distant from the frescoes, it is obvious that some cleaning activity (probably of recent occurrence in view of the small size and discreteness of the lichen thalli) has distributed lichen propagules from an innoculum, or dispersed them from existing thalli, to create distinctive areas of lichen invasion which arc across the frescoes.

Lichens are now being painstakingly removed from the frescoes by means of a scalpel; since each thallus removed takes with it the colour from beneath, it is necessary to meticulously repaint each area so exposed. This is labour-intensive, taking many weeks to cover just a few square metres. The use of liquid chemicals to control the lichen is out of the question in view of the water-based nature of the paint; perhaps a gas could be used, but those known to kill lichens would also be detrimental to the frescoes.

(6) Ostia Antica

This magnificent site is rich not only archeologically but also lichenologically: tufo, travertino and brick building materials all provide ideal substrata for crustose and foliose species; brick and plasterwork also support the fruticose *Roccella phycopsis,* a maritime lichen more commonly found on rocky shores, particularly on the back wall of the Capitolium where it densely clothes the brickwork in association with *Dirina massiliensis* s.str.; *Roccella phycopsis* is also found on inner walls of houses, where it is clearly damaging frescoes, and occasionally elsewhere. The frescoes in the houses along Via Diana were also colonized by at least six crustose species which were naturally causing disfigurement: suitable protection for these frescoes is a prerequisite for their conservation.

The walls in and around Porta Laurentina were investigated in some considerable detail, especially since some of the characteristic walling, constructed of small tufa blocks, heavily mortared together, is in poor condition, largely due to vascular plant action (particularly by *Hedera helix).* However, since lichens are undoubtedly the precursors to colonization by higher plants, consideration should be given to their role in the deterioration process; *Toninia aromatica* appears to be important in this respect. In all approximately 30 lichen species were identified from the stonework of the gateway and adjacent walls: they did not appear to be contributing significantly to the deterioration of the travertine blocks, but this should be monitored in view of the archaeological importance attached to the

latter.

Some attention was also given to the Forum: much of this had been restored (and reconstructed). It was interesting to compare the lichen flora on the reconstructed parts with that on fallen masonry. The bases of the columns were almost completely colonized by calcareous lichens (mainly *Caloplaca* spp.), but the columns themselves were devoid of lichens with the exception of the mortarwork used in the reconstruction. The reconstructed pavements, where untrodden, supported a flora composed mainly of *Aspicilia calcarea, Caloplaca citrina, C. aurantia* and *Lecanora pruinosa;* the differences, often only subtle, between floras of original and reconstructed stonework can be detected in the field, but more quantifiable data are necessary before a technique based on recognizing these differences could be employed, for example, in relative dating.

In situ terracotta storage pots, sunk into the ground to their shoulders, gave cause for concern: they were unquestionably deteriorating, mainly due to the action of crustose and squamulose lichens operating in a manner similar to that described at site 4 above. The 25 cm of neck of each pot appearing above ground level was heavily colonized by lichens, but there was a considerable variation in the flora from pot to pot, indicating differences in the composition of the terracotta; those bearing *Lecanora atra,* for example, were quite obviously blistering, the crumbling lichens falling away with attached substratum, 2-3 mm in thickness, the crowding of apothecia acting in a manner similar to that previously described for *Lecanora muralis.*

(7) Isola Sacra

Attention here was mainly directed towards a comparison of the lichen floras of treated and untreated terracotta panels of cappuccine tombs. All panels (50 cm high) supported a limited flora consisting of small colonies, widely spaced, of *Lecanora pruinosa* and *Diplotomma epipolium,* with occasional thalli of *Caloplaca aurantia;* the effectiveness of chemical treatment, in terms of lichen removal, was inconclusive. A large sarcophagus was also examined: the flora was species-poor, and those lichens present were almost entirely influenced by the considerable quantities of cement used in its reconstruction. The other buildings of the necropolis warrant further lichenological investigation in view of their archaeological importance.

Concluding remarks

The above work, based on field observations in Central Italy, constitutes the necessary first phase of any long-term research programme aimed at quantifying the actual role played by lichens in the deterioration of a wide range of archaeological materials. Stone- and art-work in exposed and partially-enclosed situations, giving rise to a variety of environmental conditions, have been examined in detail in order to identify the relationships between particular lichen species and the physical and chemical nature of their substrata and to determine the relative im-

portance of those species in biodeterioration processes obtaining in specific circumstances. It is necessary to determine, for example, which species are disfiguring but intrinsically harmless, and which cause actual physical damage. This work has produced strong evidence to suggest that recent environmental changes have been conducive to increasing detrimental invasion by certain aggressive lichen species. Such evidence would help to explain why it is that monuments, undamaged for many centuries, appear to be vulnerable to lichen attack, in addition to the known problems resulting from air pollution, in recent years.

It is self-evident that such base-line work is a prerequisite to (1) laboratory research designed to establish the nature of the interface between problematic lichens and their substrata, and (2) field trials intended to test the relative effectiveness of differing techniques and treatments for the removal and discouragement of lichens from stonework. Any treatment should be selected with care, since although immediately effective, the long-term effects may well be deleterious (Richardson 1973). Mechanical methods involving scraping and brushing, usually followed by washing, are tedious, damaging and often ineffective. Absorbed water may adversely affect the monument, particularly under fluctuating temperature regimes; penetration can be minimised by the use of water repellants, but entrapped water and rising damp can prove highly destructive. A wide range of biocides have been employed, many of which have since been rejected due to side-effects such as crystallization of soluble salts which have penetrated the stonework, staining and discolouration of monuments where the chemicals used have interacted with particular metals present in the substratum, and the promotion of secondary biological growths, which may be even more unsightly than the primary growths. Futhermore, regular treatments are likely to be necessary which are expensive both in terms of the chemicals used and the labour employed for the mechanical removal of only partially detached and brittle lichen growths which remain. The biocides employed may also be harmful to the operators and, not surprisingly, dangerous to wildlife. Some success has been achieved using organo-metallic compounds, quaternary ammonium compounds and borates, but the latter have proved problematic when used in air-polluted environments where, of course, many of the monuments it is desired to conserve are to be located.

The subtle colouration of a varied lichen mosaic can have aesthetic appeal, providing it does not produce disfigurement or unduly obscure detail, and it may also afford a protective barrier, shielding the stonework from external weathering agents. Furthermore, the different lichen communities established on monuments not only reflect the various materials employed in their construction but also can often be correlated to the chronology of successive building phases, therefore assisting in archaeological interpretation.

In the light of the above, any decision to remove lichens from stonework must not be undertaken over-hastily or without very careful consideration of the wider implications and long-term effects. Unfortunately, it has to be acknowledged that the problem is under-researched and much of the work published to date is

of a largely empirical nature which has yet to be adequately substantiated by long-term experimentation. It remains for future generations to judge the relative effectiveness of the various conservation techniques currently employed.

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Bibliography

Del Monte M. & C. Sabbioni, 1987. *A study of the patina called "scialbatura" on imperial Roman marbles.* Studies in Conservation, 32: 114-121.

Giacobini C., Nugari M.P., Micheli M.P., Mazzone B. & M.R.D. Seaward, 1986. *Lichenology and the conservation of ancient monuments: an interdisciplinary study.* In Barry S., Houghton D.R., Llewellyn G.C. & C.E. O'Rear. (eds) *Biodeterioration 6:* 386-392. Slough: CAB/International Mycological Institute.

Jones D. & M.J. Wilson, 1985. *Chemical activity of lichens on mineral surfaces - a review.* Int. Biodeterioration, 21: 99-104.

Krumbein W.E. & C.E. Schönborn-Krumbein, 1987. *Biogene Bauschade. Anamnese, Diagnose und Therapie in Bautenschutz und Denkmalpflege.* Bautenschutz Bausanierung, 1: 14-23.

Richardson B.A., 1973. *Control of biological growth.* Stone Industries 8: 22-26.

Seaward M.R.D., 1982. *Lichen ecology of changing urban environments.* In Bornkamm R., Lee J.A. & M.R.D. Seaward (eds.) *Urban Ecology:* 181-189. Oxford: Blackwell Scientific Publications.

Seaward M.R.D., 1987. *Effects of Lichens on Italian Monuments: A Field Study.* University of Bradford.

Seaward M.R.D., 1988. *Lichen damage to ancient monuments: a case study.* Lichenologist 20: 291-294.

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SOME OBSERVATIONS ON THE ESTABLISHMENT OF THE LICHEN *CALOPLACA AURANTIA* ON CONCRETE TILES IN ISRAEL

J. GARTY

Keywords: Algae, Ascospores, *Caloplaca aurantia,* colonization, SEM, tiles, *Trebouxia.*

Abstract. This paper investigates the colonization of concrete tiles by the lichen *Caloplaca aurantia* in a rural, non-polluted settlement in Israel. The percentage colonization by this crustose lichen on roof tiles 30, 45, and 60 years old was found to be 2.464 ± 0.732%, 22.972 ± 7.311% and 48.515±6.781% respectively. Scanning Electron Microscopy (SEM) revealed that spherical cells of a unicellular green alga, probably *Trebouxia* colonize pits on the weathered surface of the very same concrete tiles, as do also the ascopores of *C. aurantia.* In many of the pits, the ascospores arrange in clusters of 8 units. Fungal hyphae were observed close to ascopores and to the free algal cells.

Introduction

The roof tiles on houses built in Israel during the present century are most commonly made of concrete. Many such tiles, which are currently 60-70 years old, are covered mainly with the lichens *Caloplaca aurantia* (Pers.) var. *aurantia, Lecanora dispersa* (Pers.) Sommerf. f. *dissipata* (Nyl.) B. de Lesd., *Protoblastenia immersa* (Web.) Stein and *Candelariella aurella* (Hoffm.) Zahlbr.

The present study was a part of a wider investigation on lichen formation in nature. The focus here was on epilithic crustose lichens, making use also of Scanning Electron Microscopy (SEM). Another goal was to estimate the rate of coverage of concrete tiles by epilithic lichens in a rural non-polluted settlement in Israel.

Materials and methods

The observations relating to the present investigation were made in a rural settlement of about 8000 inhabitants (Magdiel, Hod Hasharon) located 20 km. NE of Tel-Aviv. Tile coverage by *Caloplaca aurantia* was assessed by photographing a 50 x 50 cm area on the west-facing slope of selected roofs of one-storey buildings. To do this in each case, we used a wooden frame (50 x 50 cm.) which was temporarily affixed to the roof surface. Color photographs of the areas enclosed by such wooden frames were obtained and these were then copied by a document

photocopy machine, enlarged two-fold, and weighted precisely by an electronic balance. Any areas of the photocopies showing thalli of *C. aurantia* were carefully snipped out with scissors and weighted separately. The percentage of the lichen coverage was then calculated by the formula:

$$\frac{\text{Weight of the paper representing the lichen area}}{\text{Weight of the paper representing the entire 50x50 cm. area.}} \times 100$$

The roofs selected for photography were 20, 45, and 60 years old. Ten roofs from each of these age categories were sampled by three different photographs per roof, yielding a total of 90 photocopies.

In order to ascertain whether free components of lichens existed on the photographed roof tiles, we actually collected samples of tiles from the west-facing slopes of Magdiel's 30,45 and 60 year old roofs.

In all these tile samples, the lichen coverage was less than complete, which enabled easy study of bare areas on which lichenization could occur.

The collected tiles were next fractured to yield bare chunks of about 0.5x0.5 cm each, the idea being that free lichen components and contacts between ascospores and photobiont cells would be detectable close to the established thalli of the nearest lichen colonizing the tile shards.

Samples from these seemingly bare fragments of tile were fixed overnight with 3% glutaraldehyde in 0.1 M cacodylate buffer, pH 7.4, washed with the same buffer, dehydrated by increasing concentrations of ethanol, dried with a critical point drier and finally coated with gold. The samples were then subjected to a Jeol-35 scanning electron microscope operating at 25 KV.

Results

From a chronological standpoint, the rate of lichen colonization on the tiles during the first 30 years was found to be relatively slow (2.464 ± 0.732%) but this increased to 22.972 ± 7.311% after 45 years and attained 48.515 ± 6.781% after 60 years. The observed differences in the coverage percentage were highly significant by Student's t-test for all the three age-categories of tiles ($p < 0.001$).

Fig. 1 - Fractured apothecium of *Caloplaca aurantia* growing on a 30-year-old concrete tile. Bar = 100 µm.

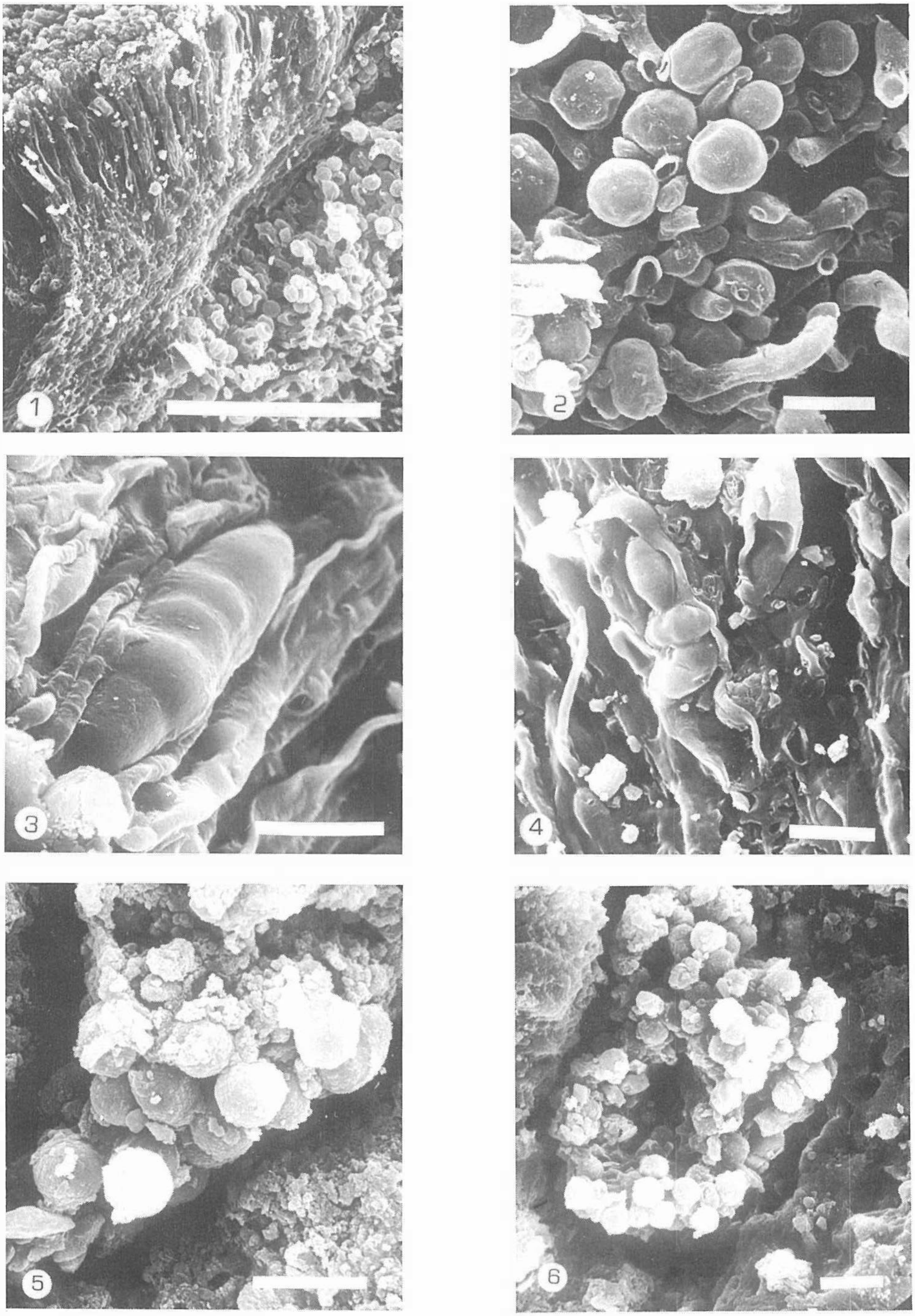
Fig. 2 - Photobiont and mycobiont cells as in Fig. 1 but shown in higher magnification. Bar = 10 µm.

Fig. 3 - Ascus and paraphyses of the hymenium of *C. aurantia*. Bar = 10 µm.

Fig. 4 - Immature *C. aurantia* ascospores still in the ascus. Bar = 10 µm.

Fig. 5 - Upper surface of a seemingly bare part of a 30-year-old concrete roof tile. Note the rough outer surface of the algal cells. Bar = 10 µm.

Fig. 6 - A group of unicellular algal cells in a pit on the surface of a 45-year-old concrete tile. Bar = 10 µm.


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The coefficient of variation, C.O.V., $\frac{(S.D.)}{\bar{x}}$ was 0.29 for the 30 years-old tile, 0.31 for the 45 year-old tile and 0.13 for the 60 year-old tile.

Fig. 1 offers a SEM view of a fractured apothecium of the lichen *Caloplaca aurantia* growing on a 30 year-old concrete tile from a roof in Magdiel. This figure shows the spherical cells of the unicellular green alga *Trebouxia* as well as a lateral view of the hymenium and a part of the disc surface. The sizes of the algal cells are presented in a higher magnification in Fig. 2, where they are seen to vary between 5 and 10 μm. One ascus and several paraphyses are shown in Fig. 3, while three ascospores, probably immature, are shown in Fig. 4.

A view of the bare surface of a concrete tile picked from among established colonies of *C. aurantia* is given in Fig. 5. A spherically-shaped unicellular green alga was found to colonize pits on the weathered surface of such tiles. These algal cells, the only kind of free unicellular green alga on the tiles, measured 5.5 - 8.5 μm in diameter and invariably displayed a rough external surface (Figs. 5-10, 13-15). As can be noted from Fig. 5 and 6, tile surfaces are smooth on their inside, probably due to the abrading chemical action of the algal lithobionts on the carbonates of the concrete tile.

The established colonies of *Caloplaca aurantia* bear numerous apothecia. These produce large numbers of ascospores which are entrapped in pits on the surface of the 60 year-old tiles (Fig. 7) as well as on those aged 30 and 45 years (Fig. 8 and 9 respectively). The spore shapes and sizes match those given by Galun (1970) for the ascospores of *Caloplaca aurantia.* In many of the pits on the bare upper surface of tiles taken from 30, 45 and 60 year-old roofs, clusters of 8 ascospores can be seen (Figs. 10-12). Frequently fungal hyphae (or ascospores) and free algal cells are seen in the same pit (Figs. 12-14). Some ascospores with shrunken walls

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Fig. 7 - Free algal cells, presumably of *Trebouxia*, and an ascospore of *C. aurantia* inside a pit of a 60-year-old concrete tile. Bar = μm.

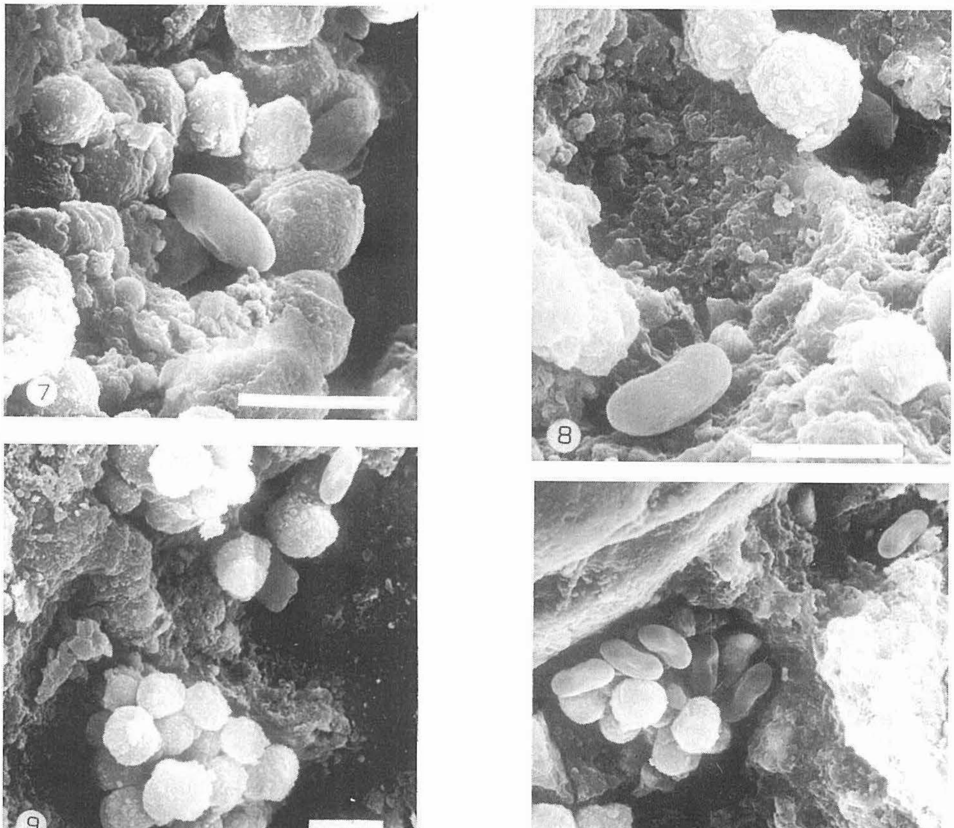
Fig. 8 - An ascospore of *C. aurantia* and some algal cells inside a pit of another 30-years-old tile. Bar = 10μm.

Fig. 9 - Free photobiont and *C. aurantia* ascospore inside a large pit on the surface of a 45-year-old tile. Bar = 10 μm.

Fig. 10 - A view of a bare area on the upper surface of a 30-year-old concrete tile. Note 8 ascospores produced and dispersed by *C. aurantia* lying close to a group of algal cells growing in the same pit. Bar = 10 μm.

Fig. 11 - Eight ascospores of *C. aurantia* inside a large pit on a 45-year-old tile. Dust particles in a variety of shapes and sizes are deposited in the same microniche. Bar = 10 μm.

Fig. 12 - Eight ascospores of *C. aurantia* inside a large pit on a 60-year-old tile. Most of the ascospores are located in small depressions in the described niche. Note fungal hyphae in the same pit. Bar = 10 μm.


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can be observed as well (Fig. 15). Clusters of free *Caloplaca aurantia* ascospores are located, however, also in pits which are not colonized by algal cells (Fig. 16).

Discussion

It is especially noteworthy that the lichen coverage of the 30 year-old tiles was a mere 2.464 ± 0.732% whereas tiles which were 45 years old showed nine times as much coverage. This means that the dispersal of lichen components, i.e. of ascospores and algae, increases considerably during the 15-year span between the tile ages of 30 and 45. It is possible that the observed increase of coverage is associated with an enhancement of weathering processes on the tile surface, for pits and ruts are known to act as traps for dust, bird droppings, water, algal cells and ascospores.

In a roof-slope situation, this is especially important, because once the *C. aurantia* ascospores have dispersed in the pits they can germinate under favorable conditions.

The coverage of the 60 year-old tiles by *C. aurantia* is about twice as much that on the 45 year-old tiles. Possibly the slower lichen colonization rate on the tiles is linked to the morphology of the substrate surfaces, for we have noted that on old tiles (50-60 years old) the pits and ruts are larger and bigger than on younger tiles. We have indeed never observed a lichen coverage of 100% on any of the 70 to 75 year-old tiles in the studied rural and non-polluted area. Many of the roofs here were in fact hardly colonized by lichens.

All this suggests that because of the enhanced weathering processes, the pits and ruts on very old tiles become too big, so that lichen-free components can no longer be trapped on the roof slopes, especially during heavy showers.

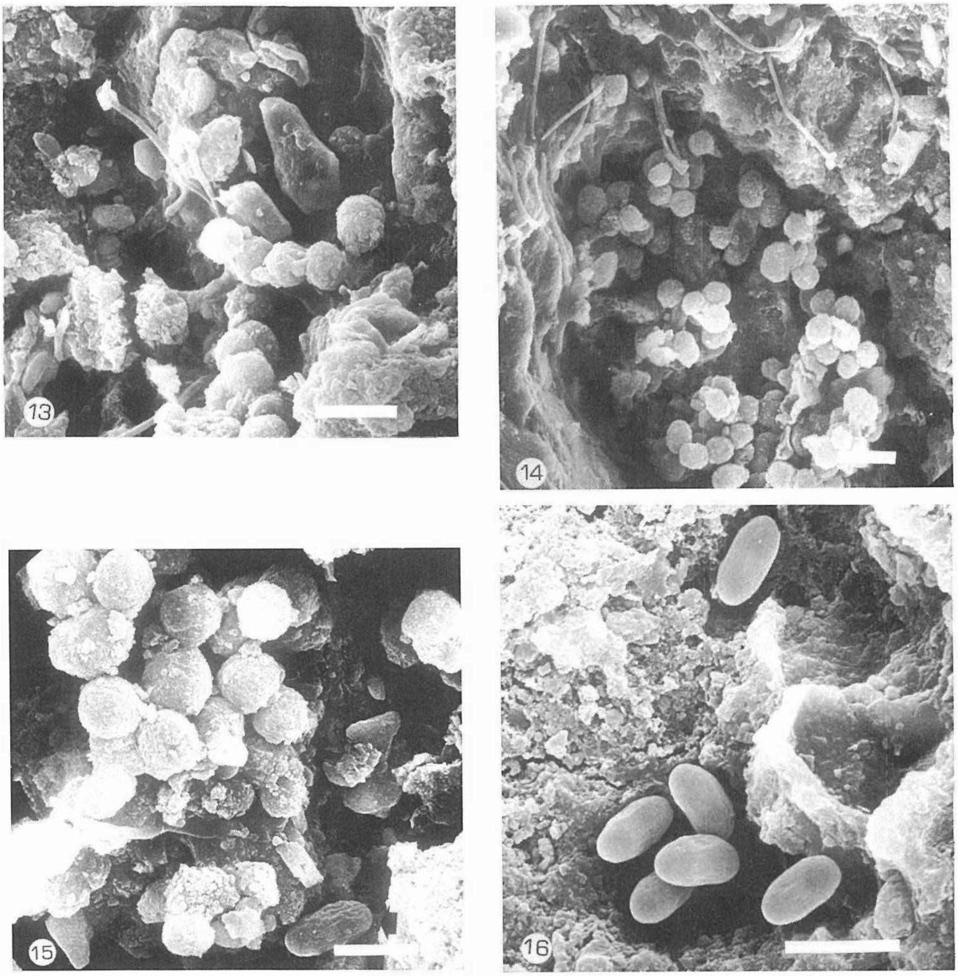
The fact that lichen ascospores were often found in clusters of eight or thereabout agrees very well with the findings of Bailey and Garrett (1968) that under laboratory conditions the usual number of *C. aurantia* ascopores per projectile is eight. Evidently, under natural conditions as well, these ascospores are liberated from the asci of *C. aurantia* in clusters of eight. We further believe that the free-living algal cells with the rough surface which we encountered were those of *Trebouxia*. Indeed, free colonies of *Trebouxia* have been reported by Nakano (1971 a; 1971 b), Tschermak-Woess (1978) and Bubrick et al. (1984).

Fig. 13 - Algal cells, fungal hyphae and dust particles inside a large pit on a 60-year-old tile. Bar = 10 μm.

Fig. 14 - *C. aurantia* ascospores (arrow), hyphae and algal cells inside a pit on a 45-year-old tile. Bar = 10 μm-

Fig. 15 - Algal cells (note their rough cell surface) and one ascospore of *C. aurantia* with shrunken walls. Bar = 10 μm. The substrate is 45 years old.

Fig. 16 - A cluster of 6 ascospores of *C. aurantia* located in a pit which is not colonized by algal cells. The substrate is 60 years old. Bar = 10 μm.



Our present findings raise two interesting questions, namely:

1) Does the rough outer surfaces possessed by the free-growing algae in the present study play a role in the recognition between these cells and the cohabitant fungal hyphae produced by the germinating ascospores of *C. aurantia*?

2) Is the outer wall surface of these algae rough because it contains binding compounds that are related to mycobiont-phycobiont recognition?

In reviewing the relevant literature, we find that Bubrick and Galun (1980 a) observed, by cytochemical means, two wall layers in trebouxioid phycobionts, and the same was observed also via cytological methods by Honneger (1982). The latter author detected protein-like particles embedded in an amorphous matrix in the outer wall of cultured *Trebouxia* cells (Honneger 1982). Subsequently she ob-

served a similar amorphous matrix also in the large mature cells of the trebouxioid phycobiont in *Cetrelia olivetorum* prior to autospore formation (Honneger, 1984. Fig. 4A).

Finally, a SEM micrograph of a group of developing aplanospores of a *Trebouxia* in the *Hypogymnia physodes* thallus, reveals that the surfaces of these cells have a rough outer coating (Fiechter and Honneger, 1988).

It is tempting therefore to conjecture that the rough surface displayed by the free unicellular green algae in the present study indicates that these cells are *Trebouxia* cells originating from established thalli of *C. aurantia.* According to Ahmadjian (1980) free-living photobionts indeed could be microcolonies derived from woospores of algae within existing lichenized associations. Hawksworth and Hill (1984) maintain that photobiont cells may be acquired:

a) from free-living algae
b) from existing thalli of other lichens or
c) from the vegetative propagules of other lichens.

The structure and composition of the cell wall surface differs in *Trebouxia* phycobionts when in symbiosis than when in the cultured, non-symbiotic state (Honneger, 1984). Similarly, differences in the cell wall surface composition between cultured and symbiotic *Trebouxia* phycobionts of *Xanthoria parietina* have been demonstrated by Bubrick and Galun (1980 b) and by Bubrick et al. (1982) via histochemical and immunological methods.

Previously, we have shown (Garty and Delarea, 1987) that on concrete tiles collected at another rural site (Ganne Am, Israel), the *Caloplaca aurantia* ascospores germinated in proximity to free algal cells very similar to those described in the present study.

Our present observations on the algal wall surface raise, however, further questions: Why is the outer surface of the *Trebouxia* cells shown in the apothecial section (Figs. 1 and 2) smooth? Is this smoothness related to fact that in this part of the lichen the fungal hyphae are relatively few? Could we conclude that these photobiont cells have very little to do with recognition of fungal hyphae? Be that as it may, we note that in the present study the algal cells of *Trebouxia,* as shown in Figs. 1 and 2, appear different both from our own free algal cells as well as from the *Trebouxia* and trebouxioid cells of other investigations cited by us, which act as photobionts in the vegetative thalli.

Several of our micrographs show numerous fungal hyphae inside the pits and ruts on the tile surfaces. In epiphytic lichens it has been shown (Jahns et al., 1979) that the algal cells form clumps that are intimately associated with long fungal hyphae, the latter probably deriving from spores of the lichen *Lecanora varia,* dispersed on needles of the tree *Picea abies.* Germinated spores of the epiphytic foliose lichen *Xanthoria parietina* have been observed on tree bark and, in some cases, in close proximity to *Trebouxia* and/or *Pseudotrebouxia* cells (Bubrick et al., 1984). We believe, therefore, that on progressively older tiles the presence of fungal hyphae in the same microniches as algal cells probably signifies the initiation of lichenization.

Acknowledgement

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References

Ahmadjian V., 1980. *Separation and artificial synthesis of lichens.* In: Cellular interactions in Symbiosis and Parasitism. Ohio State University Biosciences Colloquia, 5: 3-25, C.B. Cook, P.W. Pappas & E.D. Rudolph, eds. Ohio State University Press.

Bailey R. & R.M. Garret, 1968. *Studies on the discharge of ascospores from lichen apothecia.* Lichenologist, 4: 57-65.

Bubrick P. & M. Galun, 1980a. *Protein from the lichen Xanthoria parietina which binds to phycobiont cell walls. Correlation between binding patterns and cell wall cytochemistry.* Protoplasma, 104: 167-173.

Bubrick P. & M. Galun, 1980b. *Symbiosis in lichens: differences in cell wall properties of freshly isolated and cultured phycobionts.* FEMS Microbiol. Lett, 7: 311-313.

Bubrick P., Galun M., Ben-Yaacov M. & A. Frensdorff, 1982. *Antigenic similarities and differences between symbiotic and cultured phycobionts from the lichen Xanthoria parietina.* FEMS Microbiol. Lett., 13. 435-438.

Bubrick P., Galun M. & A. Frensdorff, 1984. *Observations on free living Trebouxia de Puymaly and Pseudotrebouxia Archibald. and evidence that both symbionts from Xanthoria parietina (L.) Th. Fr. can be found free living nature.* New. Phytol., 97: 455-462.

Fiechter R. & R. Honneger, 1988. *Seasonal variations in the fine structure of Hypogymnia physodes (Lichenized Ascomycetes) and its Trebouxia photobiont.* Pl. Syst. Evol., 158: 248-263.

Galun M., 1970. *The Lichens of Israel.* The Israel Academy of Sciences and Humanities. Jerusalem. 116 pp.

Garty J. & J. Delarea, 1987. *Some initial stages in the formation of epilithic crustose lichen in nature: a SEM study* Symbiosis, 3: 49-56.

Hawksworth D.L. & D.J. Hill, 1984. *The Lichen-Forming Fungi.* Blackie, Glasgow and London. 168 pp.

Honneger R., 1982. *Ascus structure and function, ascospore elimination and phycobiont cell wall type associated with the Lecanorales (Lichenized Ascomycetes).* J. Hattori bot. Lab., 52: 417-429.

Honneger R. 1984. *Cytological aspects of the mycobiont relationship in Lichens.* Lichenologist, 16: 111-127.

Jahns H.M., Mollenhayer D., Jeninger M. and D. Schonborn, 1979. *Die Neubesiedlung von Baumrinde durch Flechten.* I. Natur und Museum, 109: 40-51.

Nakano T., 1971a. *Subaerial algae of Patagonia South America.* I. Bulletin of the Biological Society of Hiroshima University, 38: 2-12.

Nakano T., 1971b. *Some aerial and soil algae form the Ishizuchi mountains.* Hikobia, 6: 139-152.

Tschermak-Woess E., 1978. *Myrmecia reticulata as a phycobiont and free living Trebouxia - the problem of Stenocybe septata.* Lichenologist, 10: 69-79.

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EFFETS DE LA POLLUTION ATMOSPHERIQUE SUR LA VEGETATION LICHENIQUE DES MONUMENTS HISTORIQUES

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Keywords: air pollution, fertilizers, France, lichens, limestone, monument, nitrogenous, vegetation.

Abstract: Air pollution has a direct influence on stone decay but also and indirect one by favouring lichen development. This is specially perceptible for nitrophilous lichens which proliferate on rain-exposed walls. Thus an historical monument, Notre-Dame de l'Epine's Basilica, was colonized by nitrophilous lichenic population between 1975 and 1980. These nitrophilous species with orange and yellow thallus are responsible for the disfigurement of the Basilica. The spread of nitrophilous lichenic populations is related to a recent increase in the use of fertilizers and, above all, to the recent methods of spraying fertilizers.

Introduction

Les monuments historiques sont souvent détériorés par les conditions de l'environment. Les pierres utilisées par la construction subissent des dégradations liées aux conditions climatiques locales, à l'activité biologique due aux oiseaux, aux plantes, aux lichens et aux microorganismes, et à la pollution atmosphérique. Globalement il en résulte une altération appelée ''maladie de la pierre'' (stone illness). Mais si la pollution atmosphérique intervient directement sur la dégradation de la pierre, elle intervient aussi comme facteur écologique responsable de l'installation des lichens.

Habituellement, la pollution atmosphérique est considérée comme un facteur limitant à l'installation des lichens. Si cela est vrai pour les lichens épiphytes, des nuances sont à apporter en ce qui concerne la végétation lichénique des monuments. En effet, le calcaire qui est une pierre souvent utilisée pour la construction des monuments est colonisé par les lichens, même dans le villes où la végétation épiphyte est inexistante. Cela est dû aux conditions microclimatiques existant à l'interface du calcaire et de l'atmosphère. Il se crée localement une atmosphère riche en dioxyde de carbone, qui neutralise l'acidité atmosphérique et permet ainsi l'installation des lichens. A la longue, cependant les lichens disparaissent et seuls des peuplements de microorganismes survivent.

Par contre la pollution azotée a un effet beaucoup plus visible sur la végétation lichénique, en favorisant le développement de peuplements nitrophiles. Un exemple typique est celui de la basilique Notre-Dame de l'Epine. C'est cet exemple que nous développerons ci-après.

Problematique: l'enlaidissiment de la basilique Notre-Dame de l'Epine (France)

La basilique Notre-Dame de l'Epine est située dans un petit village de Champagne crayeuse, à 8 km à l'E-NE de Châlons-sur-Marne. Construite en calcaire oolithique compact, au sommet d'une petite colline (altitude 151 m), elle présente la particularité de n'être séparée des champs que par une rangée de maisons et de se trouver ainsi presque en rase campagne.

Cet édifice, construit entre 1400 et 1527, est classé monument historique et son entretien est suivi par le Laboratoire des Monuments Historiques de Champs-sur-Marne. Le Laboratoire des Monuments Historiques est notamment chargé de l'étude des aspects microbiologiques de l'altération des pierres.

Vers 1970, sont apparus, notamment sur la façade W, des peuplements lichéniques orangés et verdâtres qui nuisent à l'esthétique de la basilique. Entre 1975 et 1980, l'extension considérable de ces peuplements a amené le Laboratoire des Monuments Historiques à nous contacter, et nous avons entrepris une étude écologique de ces peuplements lichéniques.

Le problème était de déterminer le cause du développement récent des lichenes sur la façade W et de proposer éventuellement un remède au problème d'esthétique.

Dans un premier temps, nous avons effectué une étude approfondie de la végétation lichénique de la basilique (Deruelle et al., 1979) et nous avons mis en évidence la double influence des substances azotées et du mouillage du substrat par les eaux de pluie sur l'installation des peuplements lichéniques nitrophiles. Ce phénomène très important et déjà souligné dans le S-E de la France par Clauzade et Roux (1975), nous a conduit, dans un deuxième temps, à entreprendre une étude des facteurs microclimatiques des principaux biotopes de la basilique et des conditions des écoulements d'eau sur les murs (Deruelle, 1983).

Methods d'etude

Analyse de la vegetation lichenique

L'analyse de la végétation lichénique a été effectuée à partir de 30 relevés phytosociologiques réalisés en utilisant les méthodes de Klement (1955) et de Braun-Blanquet (1964). Chaque relevé concerne une surface supérieure à l'aire minimale et floristiquement aussi homogène que possibile. Les divers relevés d'un même peuplement ont été réunis en un tableau (voir ci-après) où les espèces recontrées sont classées, selon leurs affinités phytosociologiques ou écologiques. Pour chaque espèce, un paramètre synthétique classique, le degré de présence, a été précisé sous forme d'un chiffre romain. Signalons ici, que pour ne pas endommager

la basilique, les prélèvements d'échantillons ont été très réduits. Toutefois, les peuplements étudiés étant constitués exclusivement par des lichens épilithiques bien visibles et de détermination relativement aisée, il est vraisemblable qu'un nombre relativement peu important d'espèces ait échappé aux relevés.

Etudes microclimatiques

Les facteurs microclimatiques ont été étudiés par plus de 4000 mesures ponctuelles effectuées pendant un an, et par des enregistrements continus.

Les mesures ponctuelles concernent la luminosité, la température du substrat, la température de surface des thalles, la température de l'air à proximité des thalles et l'humidité relative. Elles ont été réalisées selon le méthods de measures décrites par Roux (1979) dans son étude sur les peuplements lichéniques saxicoles-calcicoles du SE de la France.

Les enregistrements du mouillage du substrat on été effectués avec un tengochronographe. C'est un appareil (Fig. 1) qui comprend quatre capteurs de mouillage, un circuit électronique de détection du mouillage avec un oscillateur et un détecteur de seuil par capteur, et un enregistreur sur papier. Le principe de l'appareil (Roux, 1979-80) repose sur le fait que la mouillage de deux lames voisines du capteur entraîne la mise sous tension du détecteur de seuil et l'enregistrement de la durée du mouillage. Les capteurs installées au milieu des peuplements lichéniques traduisent fidèlement les variations de l'humidité substratique.

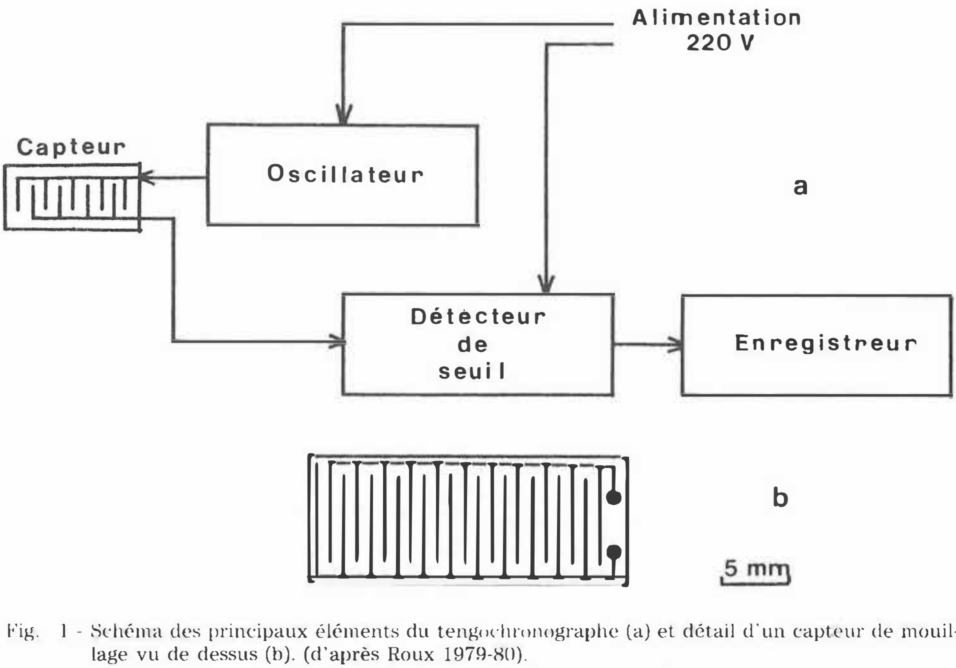


Fig. 1 - Schéma des principaux éléments du tengochronographe (a) et détail d'un capteur de mouillage vu de dessus (b). (d'après Roux 1979-80).

Resultats et discussion

Inventaire des peuplements liqueniques

Cinq peuplements lichéniques dont un avec trois faciès différents ont été déterminés sur la basilique. Les résultats sont présentés dans le tableau ci-après (Fig. 2).

L'examen des peuplements lichéniques de la basilique Notre-Dame de l'Epine nous amène à faire les constatations suivantes:

- le *Dirinetum repandae stenhammarosum* Clauzade et Roux 1975 (colonne g) est une association non nitrophile qui colonise les stations mal éclairées et protégées des écoulements des eaux de pluie par des corniches plus ou moins larges. Même s'ils altèrent la pierre sur plusieurs mm, les thalles blanc-gris du *Dirina* ne se distinguent pas du calcaire et ne sont par responsables de la détérioration de l'esthétique de la basilique.

Les peuplements de l'alliance *Aspicilion calcareae* Roux 1978 (colonne f) colonisent de faibles surfaces sur des zones légèrement inclinées (30°) et mouillées par les eaux de pluie. Ces peuplements contenant 56% d'espèces nitrophiles ont été qualifiés de peuplements hémi-nitrophiles.

- Ils sont localisés surtout à l'E et sont protégés des vents dominants d'W par la basilique elle-même, et des vents du S et d'E par des habitations situées à quelques mètres seulement de cette face E.

- les peuplements fortement nitrophiles (colonnes a à e) colonisent principalement la façace W de la basilique. Il s'agit:

de l'association à *Candelariella medians* et *Phaeophyscia nigricans* Nowak 1960 (colonne a) avec 100% d'espèces nitrophiles. Le faciès typique de cette association se développe sur les surfaces inclinées des corniches, des gargouilles ou de la base des piliers. On la rencontre aussi sur la façade W, de part et d'autre de la rosace centrale. C'est cette association riche en lichens dont la couleur varie du verdâtre à l'orangé vif, qui est responsable pour l'essentiel des traînées jaune-verdâtre qui se sont récemment développées sur la basilique.

des faciès à *Phaeophyscia orbicularis* (colonne b) et à *Xanthoria candelaria* (colonne c) de la même association. Ils se développent exclusivement sur les parois verticales vraisemblablement moins mouillées par les écoulements d'eau. La faciès à *Xanthoria candelaria* est quant à lui localisé sur la façade W de la basilique, et à sa proximité immédiate.

de l'association *Caloplacetum citrinae* Beschel 1950 ex Klement 1955 (colonne d) formant des traînées jaune-citron sur les pierres modérément mouillées par les eaux de pluie. Les thalles du *Caloplaca citrina* attirent l'oeil par leur couleur jaune vif mais leur faible développement et leur localisation réduite sur quelques pierres du chevet les rendent dans l'ensemble, moins apparents que les peuplements à *Candelariella medians* et *Xanthoria candelaria*.

de peuplements à *Caloplaca murorum* f. *tegularis* et f. *obliterata* (colonne e) qui occupent des biotopes protégés par des piliers ou par de petites corniches. Ces

Espèces	Degré de présence						
	a	b	c	d	e	f	g
Espèces nitrophiles							
Candellariella medians	V	V	IV	III	.	V	.
Caloplaca decipiens	V	IV	V	.	IV	.	.
Lecanora albescens f. monstrosula	V	II	V	.	.	.	.
Phaeophyscia orbicularis	IV	V	V	.	.	.	.
Xanthoria candelaria	IV	IV	V	.	V	.	.
Physconia grisea	.	IV	II	.	.	.	.
Caloplaca citrina	II	.	.	V	IV	V	.
Lecanora urbana	II	.	.	.	V	.	.
Caloplaca murorum f. obliterata	.	.	.	.	V	.	.
Caloplaca murorum f. tegularis	.	.	.	.	V	.	.
Caloplaca ruderum	II	.	.	III	IV	.	.
Lecanora crenulata	.	.	II	III	V	.	.
Verrucaria macrostoma	III	III	II	II	.	V	.
Caloplaca teicholyta	III	V	II	V	.	V	.
Lecanora albescens f. albescens	V	II	.	V	.	V	.
Caloplaca murorum f. pulvinata	V	II	II	.	II	.	.
Buellia epipolia v. murorum	III	.	II	III	IV	.	.
Caloplaca heppiana	V	V	II	V	.	V	.
Caloplaca aurantia	V	.	II	.	.	.	.
Physcia adscendens	.	IV	II	.	.	.	.
Caloplaca coronata	III	II	.	.	.	V	.
Lecanora hagenii	III	.	.	.	.	.	.
Lecania erysibe	.	II	.	III	.	.	.
Xanthoria parietina ssp. calcicola	.	.	IV	.	.	.	.
Lecanora dispersa	.	.	.	III	.	V	.
Lecanora dispersa f. crenulata	.	.	.	.	.	V	.
Espèces non nitrophiles							
Lecanora campestris	.	.	I	III	.	.	.
Verrucaria sp	.	.	I	.	.	.	.
Physconia pulverulenta	.	II	.	.	.	V	.
Lecanora subcircinata	.	.	.	.	.	V	.
Aspicilia hoffmannii	.	.	.	.	.	I	.
Dermatocarpon trachyticum	.	.	.	.	.	V	.
Aspicilia contorta	.	.	.	.	.	V	.
Caloplaca lactea	.	.	.	.	.	V	.
Verrucaria nigrescens	.	.	.	.	.	V	.
Dirina repanda f. stenhammari	.	.	.	.	.	.	V
Espèces nitrophiles en %	100	93	88	92	100	56	0

Fig. 2 - Composition floristique des cinq peuplements licheniques de la basilique et de leurs principaux faciès.
a) faciès typique de l'association à *Candelariella medians* et *Phaeophyscia nigricans* Nowak 1960;
b) faciès de cette même association à *Phaeophyscia orbicularis* dominant;
c) faciès de cette même association à *Xanthoria candelaria* dominant;
d) *Caloplacetum citrinae* Beschel 1950 ex Klement 1955;
e) peuplement à *Caloplaca murorum* f. *tegularis* et f. *obliterata*;
f) peuplement de l'alliance *Aspicilion calcareae* Roux 1975.

groupements recontrés quelle que soit l'exposition du substrat sont légèrement mouillés par les eaux de pluie qui apportent suffisamment de nitrates pour permettre le développement d'espèces nitrophiles. Lorsque les écoulements sont plus importants, soit naturellement à cause de la configuration des sculptures, soit artificiellement par rupture partielle d'une corniche par exemple, on observe des peuplements de transition avec l'association à *Candelariella medians* et *Phaeophyscia nigricans* Nowak 1960.

L'inventaire des peuplements lichéniques de la basilique Notre-Dame de l'Epine nous amène à constater:

1°) la présence de peuplements calcicoles déjà décrits par ailleurs mais avec des faciès nouveaux;

2°) l'abondance des peuplements nitrophiles;

3°) la liaison entre l'enlaidissement de la façade W et la nitrophilie des associations qui s'y développent.

Exigences microclimatiques des associations

Parmi les différentes associations étudiées sur la basilique Notre-Dame de l'Epine, l'association à *Candelariella medians* et *Phaeophyscia nigricans* est la plus héliophile, la plus photophile et la plus thermophile. Le *Dirinetum repandae stenhammarosum* est au contraire l'association la moins héliophile, la moins photophile et la moins thermophile, et ceci quelle que soit l'ambience climatique du moment. Les autres peuplements présentent des caractères intermédiaires.

L'écart thermique entre l'association à *Candelariella medians* et *Phaeophyscia nigricans* d'une part et le *Dirinetum repandae sthenhammarosum* d'autre part est de 2°C par temps clair et de 1°C par temps couvert. Même si la température est un facteur essentiel de la répartition des lichens, cette différence de température est ici trop faible pour expliquer la colonisation des différents biotopes de la basilique. Il en est de même pour la luminosité. Par contre un facteur semble essentiel, c'est la durée de mouillage du substrat.

Le temps de mouillage a été mesuré en continu pour quatre stations entre le mois de mars 1980 et le mois de mars 1981 (Fig. 3). L'association à *Candelariella medians* et *Phaeophyscia nigricans* est la plus mouillée pour l'ensemble de l'année. Cette importance de mouillage se retrouve chaque mois puisque pour chacun des 13 mois étudiés la durée du mouillage est la plus élevée. Le peuplement à *Caloplaca murorum* f. *obliterata* et f. *tegularis* présente le temps de mouillage le plus faible avec surtout un mouillage pendant la période hivernale d'octobre à avril. L'existence de vents dominants du N et du NE pendant l'hiver peut expliquer cette répartition hivernale du mouillage. L'association *Dirinetum repandae stenhammarosum* est également peu mouillée avec un maximum en décembre (40% du mouillage annuel). En ce qui concerne cette association on peut préciser que le thalle du *Dirina* est hydrofuge et que les gouttelettes d'eau roulent en surface sans le mouiller véritablement. Il n'en est cependant pas de même pour le capteur où les gouttelettes adhèrent en surface et déclenchent l'enregistrement. En-

fin, le faciès à *Xanthoria candelaria* de l'association à *Candelariella medians* et *Phaeophyscia nigricans* a un mouillage intermédiaire (644 h pour l'année) entre les deux associations vues précédemment (255 h et 350 h) et la faciès typique (1107 h).

Il ressort de cette étude que l'association à *Candelariella medians* et *Phaeophyscia nigricans* (faciès typique) qui possède le temps de mouillage le plus long, est en outre l'association la plus nitrophile. Le mouillage du faciès à *Xanthoria candelaria* plus faible est cependant suffisant pour permettre l'installation de lichens nitrophiles (88% d'espèces nitrophiles). A côté de cela le *Dirinetum repandae stenhammarosum* qui n'est pas véritablement mouillé par les eaux de pluie, n'est pas nitrophile.

Origine des apports azotes

Les observations phytosociologiques et les mesures du temps de mouillage du substrat, effectuées sur la basilique Notre-Dame de l'Epine indiquent que les peuplements nitrophiles occupent préférentiellement les surfaces mouillées par les écoulements d'eau. Or, les écoulements d'eau existent depui la construction de la basilique, y compris sur la façade W dont l'enlaidissement ne remonte qu'à une

Mois	Durée de mouillage en mm			
	Dirinetum repandae stenhammarosum	Peuplement à *C. murorum* f. *obliterata* et f. *tegularis*	Association à *Candellariella medians* et *Phaeophyscia nigricans* — Faciès typique	Association à *Candellariella medians* et *Phaeophyscia nigricans* — Faciès à *Xanthoria candelaria*
1980				
mars'	362	914	4641	1806
avril	128	592	4313	431
mai	154	47	3256	1021
juin	294	8	318	54
juillet	1988	22	8865	3449
août	170	0	2344	437
septembre	121	5	1528	343
octobre	843	879	6881	2375
novembre	1499	2584	5807	3400
décembre	8210	5660	10430	7400
1981				
janvier	2954	2200	5860	6777
février	1913	1604	6352	4462
mars	2386	770	5822	6661
TOTAL en heures	350 h	255 h	1107 h	644 h

Fig. 3 - Durée de mouillage des quatre peuplements retenus.
(1) enregistrement effectué pendant 10 jours (début des mesures le 22/3/80);
(2) appareil n'ayant fonctionné que pendant 3 jours (absence d'alimentation électrique).

quinzaine d'années.

Le développement rapide de l'association nitrophile à *Candelariella medians* et *Phaeophyscia nigricans* traduit indiscutablement un apport de substances azotées qui n'existait pas autrefois. C'est cette pollution azotée qui est responsable de l'enlaidissement de la façade W de la basilique.

L'existence de nombreux pigeons nichant partout sur la basilique constitue un apport non négligeable d'azote. Mais la localisation des fientes, limitée à quelques zones bien déterminées et la présence de pigeons signalée depuis très longtemps, ne peuvent justifier l'ampleur de l'expansion récente des lichens nitrophiles. Une autre source de substances azotées est constituée par les engrais employés à dose massive dans cette région de grande culture. Or, depuis une quinzaine d'années, les engrais azotés sont utilisés en Champagne sous forme liquide (nitrates) ou sous forme gazeuse (ammoniac). Les engrais liquides sont stockés dans de grandes curves entreposées dans les champs avant d'être pulvérisés. Ainsi, en moyenne 300 à 400 litres d'engrais liquides sont épandus par hectar de culture, la quantité pulvérisée variant avec la nature de la culture.

Cette technique récente d'épandage des engrais par pulvérisation est donc une source importante de pollution azotée. Sous l'action des vents dominants, des vésicules de nitrates et des particules de sol enrichies en azote nitrique ou ammoniacal sont plaquées sur la façade W de la basilique. Les pluies qui frappent directement la façade solubilisent les substances azotées et favorisent l'installation puis le dèveloppement des lichens nitrophiles. Des observations identiques ont été faites en Grande-Bretagne (Brightman et Seaward, 1977) où les mêmes espèces nitrophiles colonisent les murs des églises.

C'est donc la pollution azotée qui est responsable du développement des peuplements lichéniques nitrophiles et de l'enlaidissement récent de la basilique Notre-Dame de l'Epine. On peut attribuer cette pollution aux modalitées d'épandage des engrais par pulvérisation sous forme liquide et gazeuse.

Conclusion

Nous avons envisagé ici un cas précis où la pollution atmosphérique était responsable du développement de peuplements lichéniques sur un monument historique. C'est surtout sous cette forme de pollution azotée plutôt développée en milieu rural qu'en milieu urbain, que la pollution atmosphérique agit sur les lichens des monuments. Le développement des lichens nitrophiles très colorés est responsable de l'enlaidissement de la pierre.

Le ravalement de la basilique Notre-Dame de l'Epine a été entrepris depuis notre étude, et des traitements divers de la pierre ont été tentés. A l'heure actuelle, seule la façade W a été rénovée mais la présence de lichens sur les piliers des autres faces de la basilique et l'utilisation intensive des engrais risque d'entraîner l'installation de nouveaux lichens. Des observations régulières devraient permettre de suivre précisément une recolonisation de la façade W par les lichens.

Bibliographie

Braun-Blanquet J., 1964. *Pflanzensoziologie Grundzüge der Vegetationskunde.* Springer. Vienne et New-York. 864 p.

Brigthman F.H. et M.R.D. Seaward, 1977. *Lichens of man-made substrates.* In Seaward M.R.D. (ed.): *Lichen Ecology.* 253-293. Academic Press London.

Clauzade G. et C. Roux, 1975. *Etude écologique et phytosociologique de la végétation lichénique des roches calcaires non altérées dans les régions méditerranéenne et sub-méditerranéenne du Sud-Est de la France.* Bull. Hist. Nat. Marseille, 35: 153-208.

Déruelle S., 1983. *Ecologie des lichens du Bassin Parisien. Impact de la pollution atmosphérique (engrais, SO_2, Pb) et relations avec les facteurs climatiques.* Thèse de Doctorat d'Etat, Université Paris VI, 300 + 220 p.

Déruelle S., Lallement R. et C. Roux, 1979. *La végétation lichénique de la basilique Notre Dame de l'Epine (Marne).* Documents Phytosociologiques. N.S. 4: 217-234 e.

Klement O., 1955. *Prodromus der mitteleuropaïschen Flecthengeselleschaften.* Feddes Repertorium. Beih. 135: 5-194.

Roux C., 1979. *Etude écologique et phytosociologique des peuplements lichéniques saxicoles-calcicoles du Sud-Est de la France.* Thèse Doctorat d'Etat. Paris. 534 p.

Roux C., 1979-1980. *Etude de la durée de mouillage du substrat dans cinq peuplements lichéniques saxicoles-calcicoles de Provence.* Bull. Soc. Linnéenne Provence. 32: 65-97.

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LICHEN WEATHERING ACTIVITIES ON MINERAL AND ROCK SURFACES

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Keywords: biocorrosion, biodeterioration, biological pitting, endolithic, epilithic, lichens, limestone, sandstone.

Abstract: The biocorrosion and biodeterioration of limestone and sandstone by epilithic and endolithic lichens was studied using the maceration and the casting-embedding techniques. The investigations revealed alterations on the rock surface, characterized by biocorrosive pitting, etching patterns, imprints of the fruiting bodies, boring channels and mucilaginous etching figures. Moreover, the inside of the rock is penetrated by extensive and compact networks of the lichenized fungal hyphae. These biodeteriorations are positively correlated to the physical and chemical actions of the lichen involved as well as to the nature of the rock.

Introduction

The involvement of lichens in rock weathering has been discussed since the end of the 19. century. Aldready Julien (1883) mentioned the influence of lichens as an organic agent in the deterioration fo stone material. At the turn of the century, particularly Bachmann (1904, 1907, 1911, 1917), Smith (1921) and Fry (1927) provided studies which were concentrating on the mechanical action of lichens. Subsequently more emphasis was placed on the chemical alterations of rocks by lichen compounds (e.g. Schatz, 1962, 1963; Syers, 1969; Iskandar & Syers, 1971; Williams & Rudolph, 1974; Ascaso & Galvan, 1976; Galvan et al., 1981; Ascaso et al., 1982). However, the lichenic weathering on mineral surfaces involves both physical and chemical processes. Of these, the physical mechanism is mainly characterized by hyphae penetration and thallus expansion and contraction, whilst for the chemical action oxalic acid and several other lichenic substances are important. Many of these secondary metabolic products are powerful metal complexing agents leading to a disintegration of the rock surface (Syers & Iscandar, 1973).

Regarding the thallus morphology, crustose lichens which are in direct and intensified contact with the substratum are much more important in the biodete-

rioration of stone than foliose and fruticose lichens which are only loosey connected with the substrate (Syers & Iscandar, 1973). Furthermore, endolithic lichens although being less conspicuous, are possibly more significant in rock weathering (Krumbein, 1966, 1969; Danin et al., 1982, 1983).

The intention of this paper is to document the phenomenology of the different biocorrosive patterns of lichen-encrusted rocks as these relate to physical and chemical actions.

Material and Methods

Investigating the biodeterioration of epilithic and endolithic lichens on calcareous and siliceous rocks, both the maceration and the casting-embedding technique, were used. The lichenized rocks were macerated with "Eau De Javelle" (Schneider, 1973; Gerlach, 1984) and for the casting-embedding procedure the resins "Epon" (Golubic et al., 1970) and "Spurr" (Spurr, 1969) were applied. The samples were examined by scanning electron microscopy (SEM).

Results and Discussion

The study indicates convincingly different weathering patterns on the surface caused by the lichen investigated, and to what extent the stone is penetrated by individual endolithic hyphae.

Caloplaca heppiana (Müll. Arg.) Zahlbr.
Germany, Jewish cemetry, Rödelsee (Untefranken) 8/86 and Aurich 9/86; lichen on limestone

The activities of the crustose lichen *Caloplaca heppiana* revealed, upon maceration, etching patterns and imprints of the fruiting bodies which were easily distinguishable by the ring-shaped microgrooves as shown in Fig. 1. Besides, the penetration of hyphae into the substratum is indicated by the boring channels (Fig. 2). Longitudinal sections of the embedded samples, the "casts", when observed by SEM show the density and number of the endolithic hyphae penetrating the stone (Fig. 3). Stone lamellae perforated by fungal hyphae are documented in Fig. 4.

Acarospora fuscata (Nyl.) Arnold; *Candelariella vitellina* (Hoffm.) Müll. Arg.; *Lecanora grumosa* (Pers.) Röhl.
Germany, Jewish cemetry, Rödelsee (Unterfranken) 8/86; lichens on sandstone

Vertically sectioned sandstone encrusted with the lichens *Acarospora fuscata*, *Candelariella vitellina* and *Lecanora grumosa* as observed by light microscopy, reveals an extensive compact network of hyphae, which reaches penetration depths of up to 3 mm. At the rock/lichen interface the attacked stone material is inchoherent, evidenced by a notable increase in porosity and a decrease in stability between the structural components leading to a lifting of the surface. This deterioration phenomenon, formerly assumed as abiogenic was called "swelling"

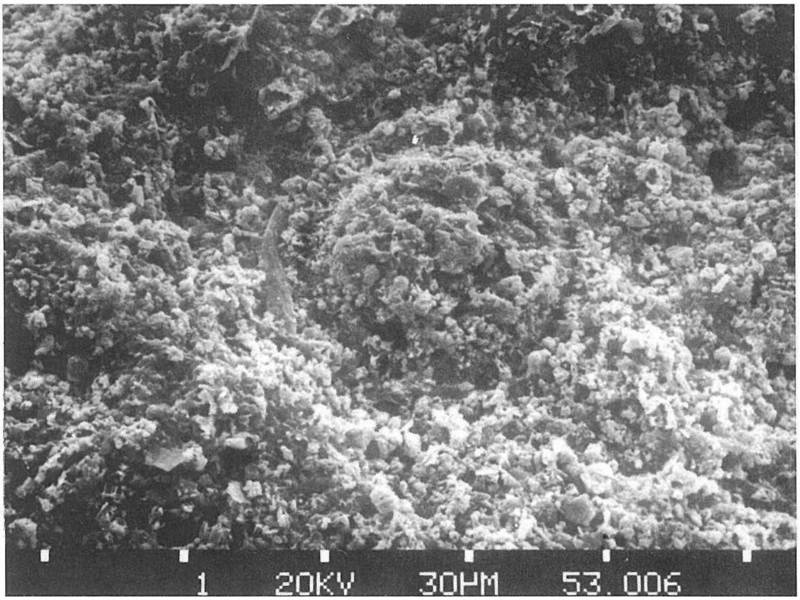


Fig. 1 - x 670. Macerat of *Caloplaca heppiana*. SEM-photo showing a print of an apothecium with and individual hyphae (on the left) penetrating the limestone

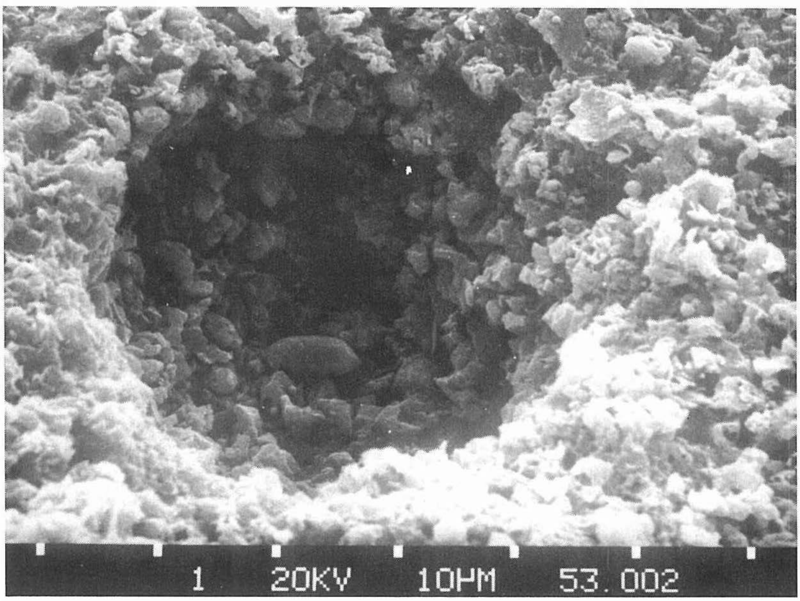


Fig. 2 - x 1700. Detail of Fig. 1; pit with a boring channel as connection to the inside of the stone.

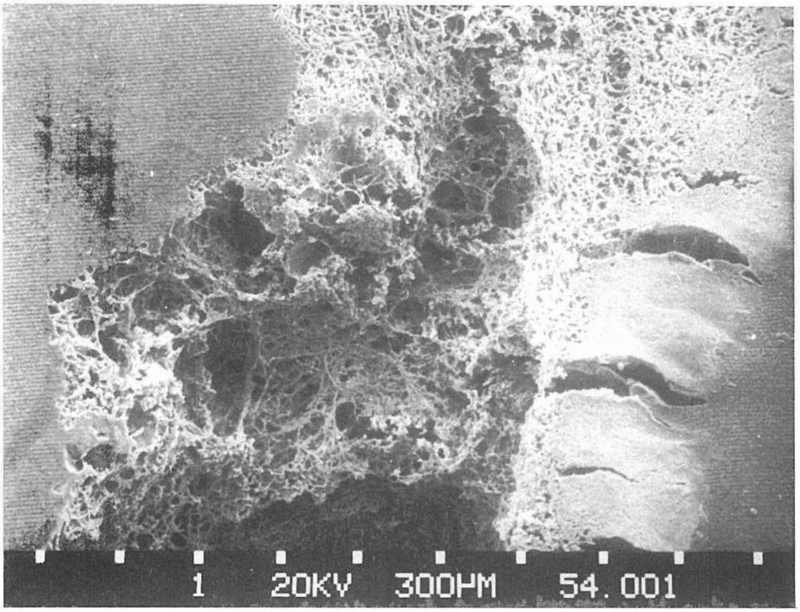


Fig. 3 - x 700. Hyphae of *Caloplaca heppiana*, SEM-photo, cast, showing by partial removal of the rock, how the hyphae penetrate through the stone lamellae.

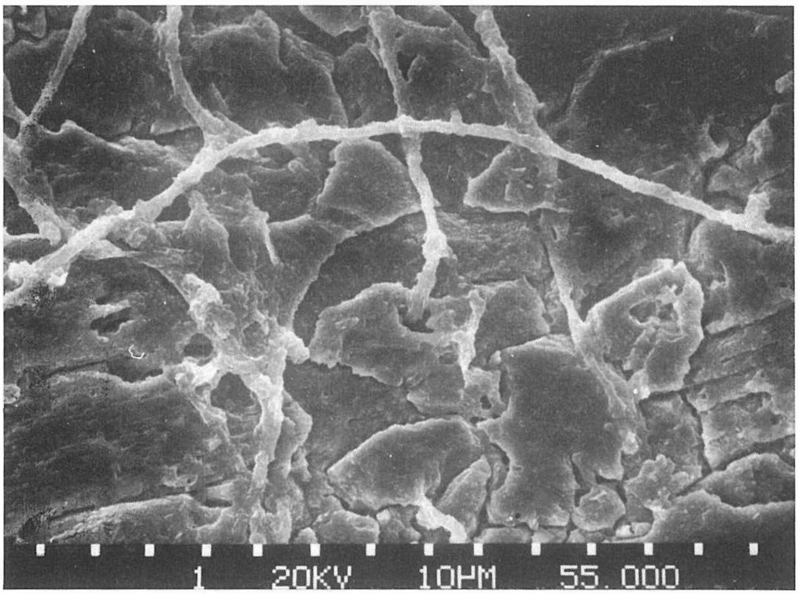


Fig. 4 - x 40. Cross section through the thallus of *Calоplaca heppiana*, SEM-photo, cast. A compact network of endolithic hyphae penetrating the rock.

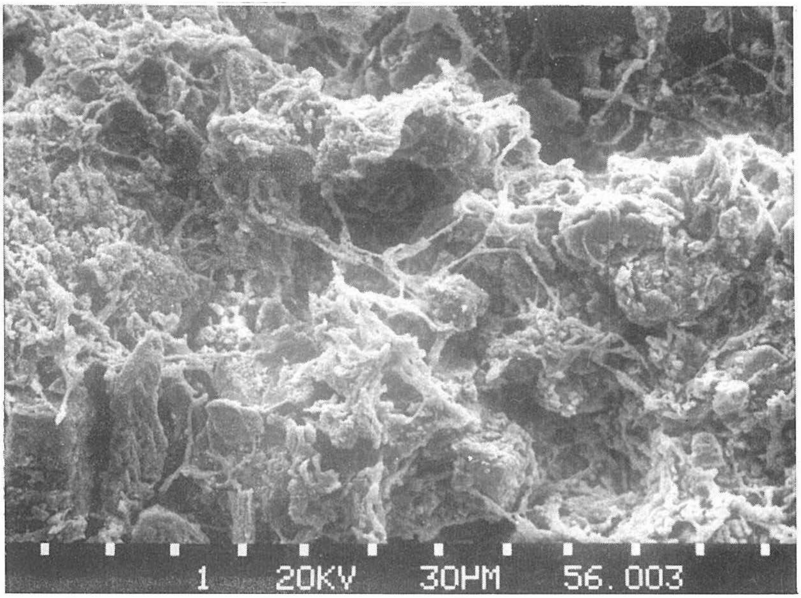


Fig. 5 - x 300. *Candelariella vitellina*, SEM-photo, cast. Rock matrix partially dissolved. The fungal hyphae penetrate the porous and loosened rock material.

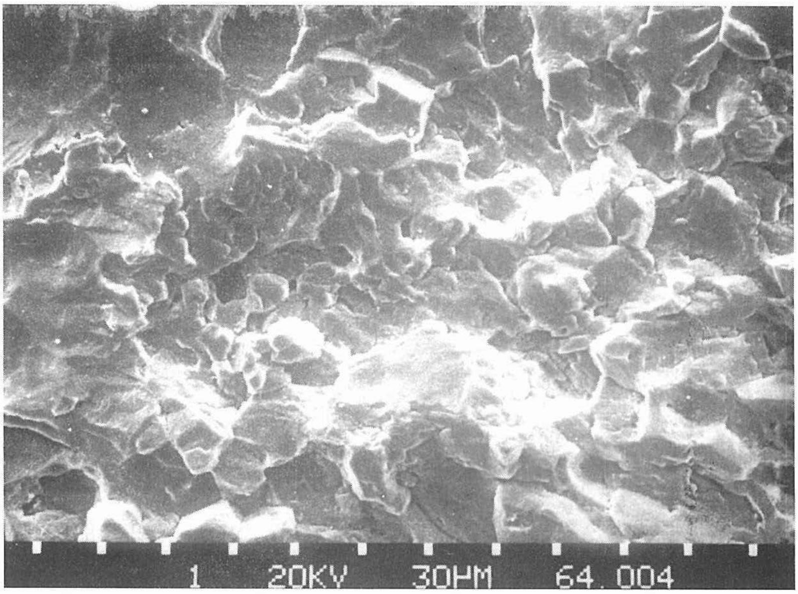


Fig. 6 - x 300. Macerate, SEM-photo. Corroded surface of quartz caused by the activity of *Rhizocarpon geographicum*.

(Torraca, 1980). Such patterns of biogenic initial stages of desquamation are also connected with the lichens *Lecanora polytropa, Lecanora rupicola, Lecanora sulphurea* and *Lecidea fuscoatra*. SEM observations of a cast with *Candelariella vitellina* show mineral fragments intensively incorporated into the lichen mycelium (Fig. 5).

Rhizocarpon geographicum (L.) DC.
Italy, Pozzuoli 8/84; lichen on quartzitic stone.

In general quartzitic rock surfaces are considered as extremely resistant to weathering. The present study demonstrates that, after removal of the lichen, the thallus/stone interface indicates significant etching patterns (Fig. 6). Comparable obsevations have been made by Hallbauer & Jahns (1977) and Jones et al. (1981). Moreover, Jones, Wilson & MacHardy correlated the biocorrosion effect more to the acidic properties rather than to the complexation effects of lichenic compounds.

Lecanora dispersa (Pers.), Sommerf.
Germany, Jewish cemetry Hamburg 9/86 and Oldenburg 4/87; lichens on limestone.

A macerated sample of this calcicole lichen indicates biogenic pits and mucilaginous etching figures on places formerly colonized by apothecia on the surface of the rock (Fig. 7). SEM examinations of the apothecia show the margins of the fruiting bodies properly encrusted with calcium oxalate (Figs. 8, 9). The biomineralisation of Ca-oxalate depends on the substrate and on the lichen involved. Amounts of up to 60 pe cent of the lichen dry weight have been observed (Syers et al. 1967). Depending on the formation conditions Ca-oxalate can occur as "whewellite" mineral, a monohydrate ($Ca_2O_4 \cdot H_2O$), or as "weddellite", a dihydrate (CaC_2O_4). The crystal form of the whewellite is plateled-shaped and that of the wheddellite is bipyramidal (Jones & Wilson, 1986). Besides, a cast of the lichen encrusted stone indicates mucilaginous excretions (Fig. 10).

Pyrenocarpous endolithic lichens
Israel, Negev 8/86; lichen on limestone.

Samples carrying several endolithic pyrenocarpous lichen species are characterized by a typical jigsaw puzzle-like pattern (Danin et al. 1982, 1983). Adjacent colonies of these lichens form micro grooves which are filled up by fungal hyphae of the neighbouring lichens (Fig. 11). SEM observations of macerated samples and casts indicate biopitting and other biocorrosive patterns evidenced by differently developed pits and holes caused by the penetration of individual hyphae and by the activity of the fruiting bodies (Figs. 12, 13). This biodeterioration pattern has already been documented by Krumbein (1969) and later by Danin et al. (1982, 1983). Additionally, chasmolithic lichens colonizing fissures and cracks inside of the rock were documented.

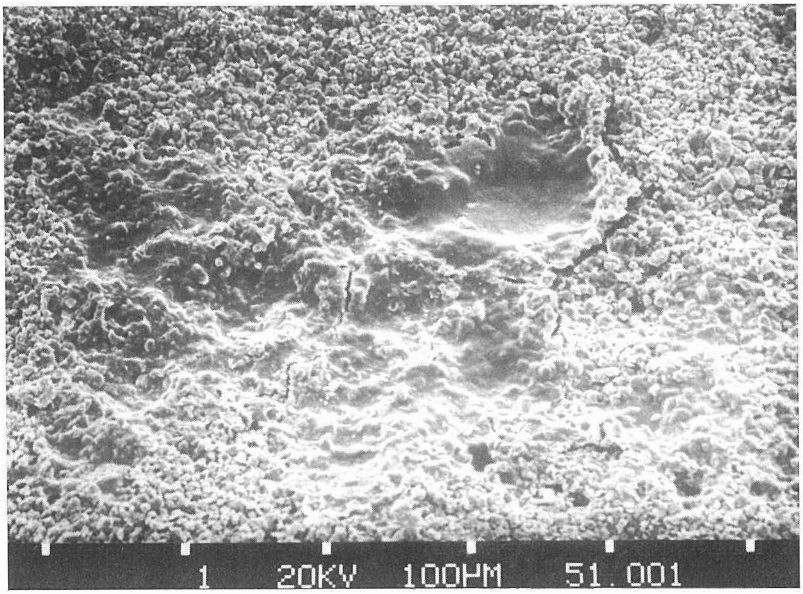


Fig. 7 - x 220. Macerate of *Lecanora dispersa,* SEM-photo, showing mucilaginous etching figures of the apothecia as well as biogenic pits.

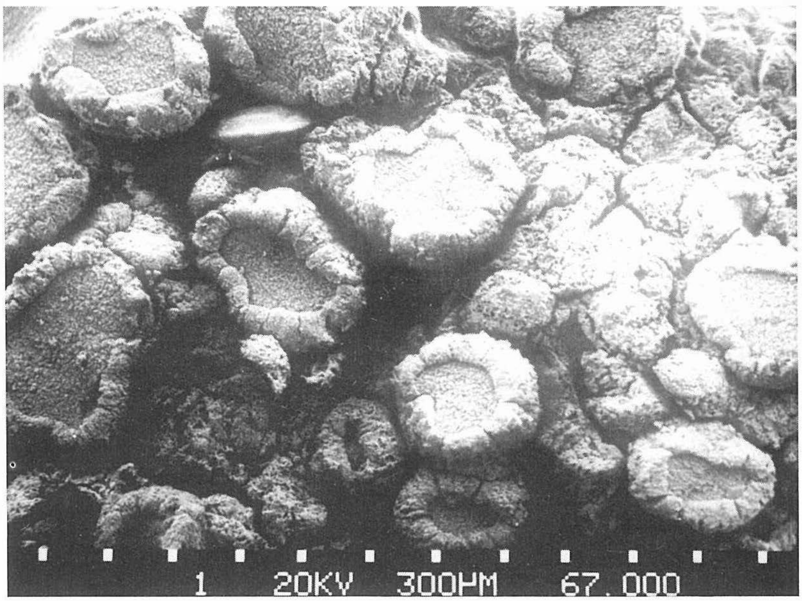


Fig. 8 - x 30. Scanning electron micrograph showing apothecia of *Lecanora dispersa.*

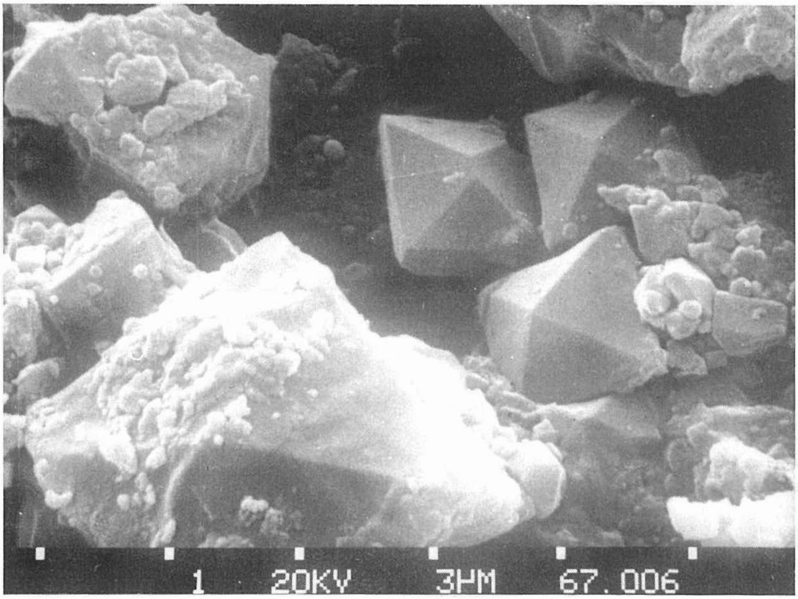


Fig. 9 - x 6600. Detail of Fig. 7. Ca-oxalate crystals with tetragonal symmetry and bipyramidal crystal form (wheddellite) on the margin of the fruiting body of *Lecanora dispersa*.

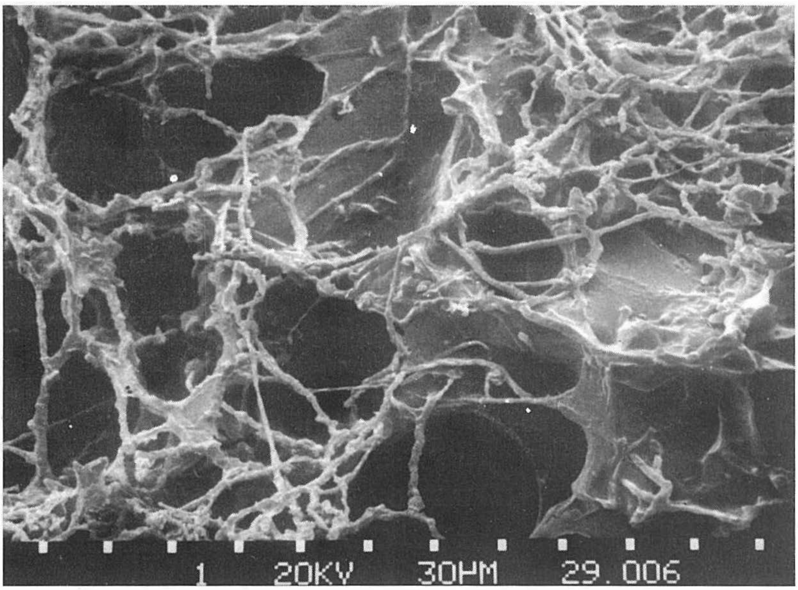


Fig. 10 - x 330. *Lecanora dispersa*, SEM-photo, cast, showing the network of endolithic fungal hyphae and mucilaginous excretions.

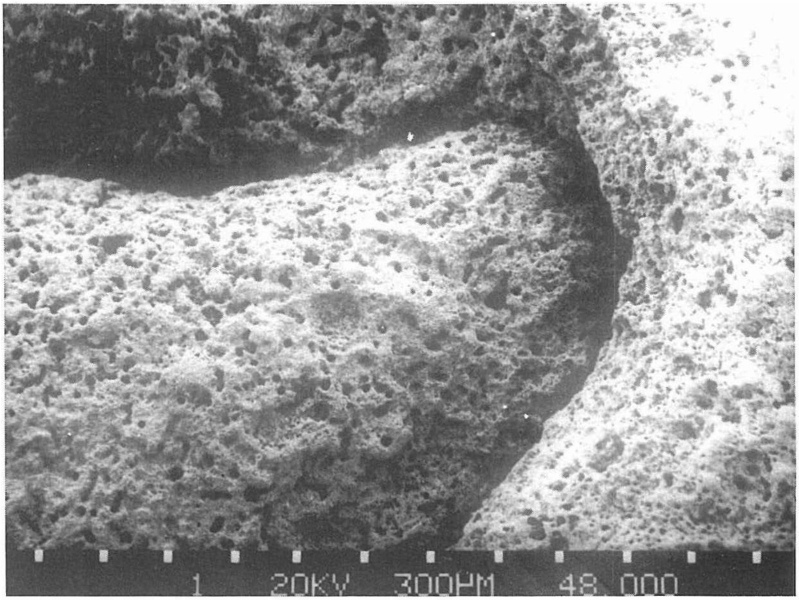


Fig. 11 - x 30. Scanning electron micrograph of a macerated sample showing a micro groove induced by the expansion and contraction of the adjacent lichen thalli as well as biogenic pits.

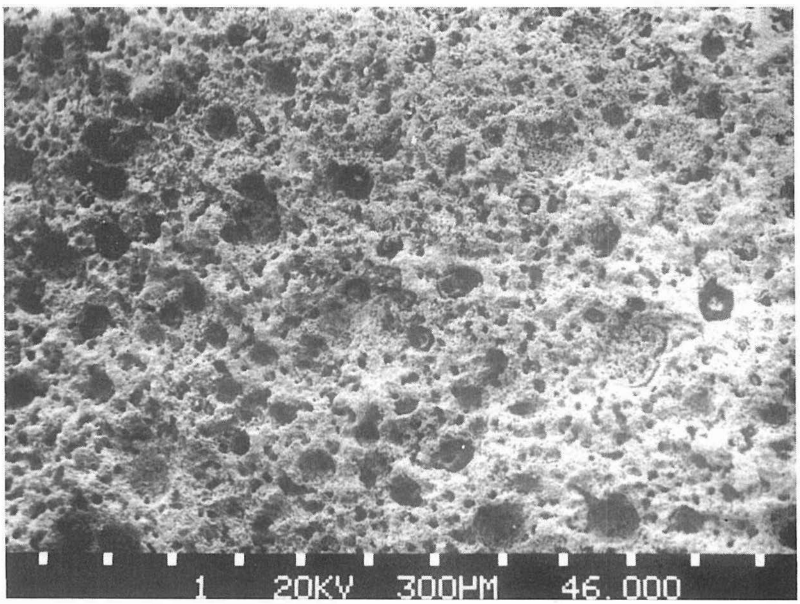


Fig. 12 - x 30. Macerate, SEM-photo, showing the pitting corrosion induced by the activity of endolithic lichens.

The weathering activities caused by epilithic and endolithic lichens were described. These deteriorations of the stones are positively connected to the physical and chemical activity of the lichen involved. Based on its poikilohydric character the thallus is exposed to large and frequent fluctuations in water content creating tensions in the thallus, compared to a pulling strain (Bachmann, 1922, 1923; Fry, 1927; Ried, 1960). These alternating processes along with the microclimate conditions (Jahns & Ott, 1983) as well as the chemical reactions bring about the diruption of rock fragments.

Lichens excrete a variety of secondary metabolic compounds. Many of these substances are powerful metal-complexing agents although differing in their chelating capacity. This fact seems to be correlated rather to the polar groups such as -OH and -COOH than to the water solubility of the compounds. In fact, the presence of the donators in ortho-position favours the formation of soluble complexes which are frequently coloured. On the other hand, oxalic acid, very common in microorganisms and plants is also widespread in lichens being concerned as a significant weathering agent (Zopf, 1907; Smith, 1921). Synthezised by the mycobiont, oxalic acid is excreted, forming hardly soluble calcium oxalate, which is an extracellular deposit (Henssen & Jahns, 1974; Schade, 1970). These calcium oxalates are derived from the dissolution of limestone, marble, dolomite but also by calcium leaching from feldspars and mica. The weathering phenomena brought about at the rock/lichen interface are etching patterns and inhomogenities like desquamation/exfoliant and sanding from the surface of the stone. Biocorrosive activity of mucus produced by the mycobiont must also be taken into consideration. In its dry state, it can produce high adhesion strenghts, leading to a reduction of cohesion and adhesion between the structural components (Fry, 1922, 1927; Eichler, 1986). Besides this, many of these mucilaginous substances are aggressive and active on the surface or degraded by acid producing bacteria (Krumbein, 1973; Krumbein & Schönborn-Krumbein, 1987). Furthermore they act like "flypaper" and particulate aerosol is caught to much larger extent on rocks colonized by epi- and endolithic lichen. These materials in turn can further contribute to biological, chemical and physical destructions on and in rocks of different chemistries and mineralogies.

The extent of rock biocorrosion underneath lichen cover and through endolithic organisms seems to be influenced strongly by the nature of the thallus and its physical and mechanical actions but also by the physical and chemical composition of the rock. Moreover, the "biomechanical" deterioration of the stone precedes its biologically or abiogenically initiated chemical decomposition, and biocorrosion precedes abiogenic corrosion processes.

Conclusions

Weathering activities by epilithic and endolithic lichens are positively connected to the thallus expansion and contraction and hyphae penetration as well as to the chelating capacities of the lichen substances and oxalic acid. Furthermore,

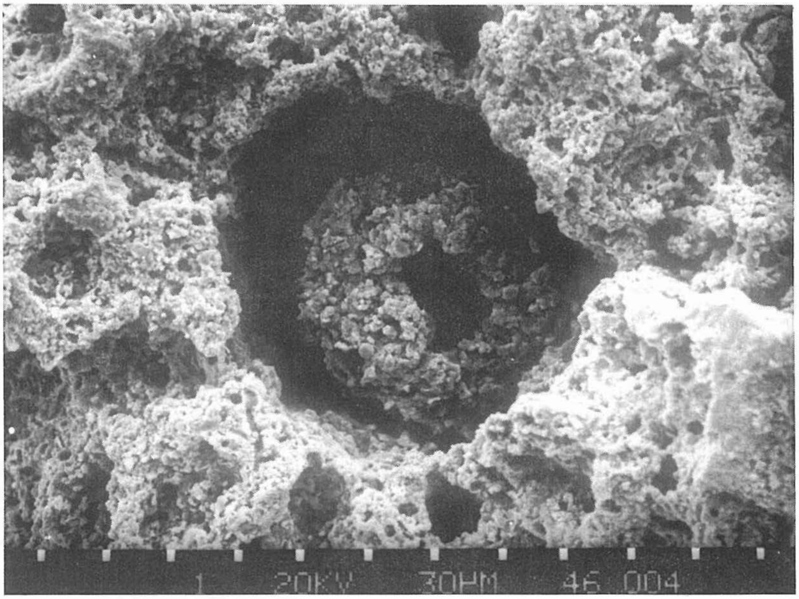


Fig. 13 - x 300. Detail of Fig. 11. Perithecium with crystalline deposit around the pore, pushing through the surface of the stone. Consider the typical pore of this fruiting body.

the intensity of rock weathering is influenced by the lichen tissue and the physical and chemical composition of the rock. Moreover, the macro- and microclimate conditions must also be taken into consideration.

Finally, the overall effect influencing the stone weathering appears in a very complex context. Obviously, one has to be careful in forwarding oversimple chemical, physical or biological theories which do not correlate with the phenomena. Following the investigations presented here, further empirical as well as analytical studies seem to be necessary in order to obtain a better understanding of both abiogenic and biogenic weathering processes although we start to understand some of the complex procedures and processes going on in the field of biogenic action by physical and chemical means and among the chemical means through the action of biogenic inorganic and organic acids or any other aggressive compound.

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Literature

Ascaso C. & J. Galvan, 1976. *Studies on the pedogenetic action of lichen acids.* Pedobiologia 16: 321-331.

Ascaso C., J. Galvan & C.l Rodgriguez-Pascal, 1982. *The weathering of calcareous rocks by lichens.* Pedobiologia 24: 219-229.

Bachmann E., 1904. *Die Beziehung der Kieselflecthen zu ihrem Substrat.* Ber. Dtsch. Bot. Ges. 22: 101-104.

Bachmann E., 1907. *Die Rhizoidenzone granitbewohnender Flechten.* Jb. wiss. Bot. 44: 1-40.

Bachmann E., 1911. *Die Beziehungen der Kieselflechten zu ihrer Unterlage. II. Granit und Quarz.* Ber. Dtsch. Bot. Ges. 29: 261-273.

Bachmann E., 1917. *Die Beziehungen der Kieselflechten zu ihrer Unterlage. III. Bergkristall und Fling.* Ber. Dtsch. Bot. Ges. 35: 465-476.

Bachmann E., 1922. *Zur Physiologie der Krustenflechten.* Z. Bot. 14: 193-233.

Bachmann E., 1923. *Untersuchungen über den Wasserhaushalt einiger Felsenflechten.* Jb. wiss. Bot. 62: 20-64.

Danin A., R. Gerson & J. Garty, 1983. *Weathering patterns on hard limestone and dolomite by endolithic lichens and cyanobacteria: supporting evidence for eolian contribution to Terra Rossa Soil.* Soil Sci. 136: 213-217.

Danin A., R. Gerson, K. Marton & J. Garty, 1982. *Patterns of Limestone and Dolomite Weathering by Lichens and Blue-Green Algae and their Palaeoclimatic Significance.* Palaeogeogr. Palaeoclimatol. 37: 221-233.

Eichler H., 1986. *Die Bedeutung der Flechten (lichens) für die geowissenschaftliche Ökosystemforschung,* pp. 81-98. In: H.J. Lippolt (ed.), Heidelberger Geowissenschaftliche Abhandlungen, vol. 6, Darmstadt.

Fry E.J., 1922. *Some Types of Endolithic Limestone Lichens.* Ann. Bot. 36: 541-562.

Fry E.J., 1927. *The Mechanical Action of Crustaceous Lichens on Substrata of Shale, Schist, Gneiss, Limestone, and Obisian.* Ann. Bot. 41: 437-460.

Galvan J., C. Rodriguez & C. Ascaso, 1981. *The Pedogenic Action of Lichens in Metamorphic Rocks.* Pedobiologia 21: 60-73.

Gerlach D., 1984. *Botanische Mikrotechnik.* Georg Thieme Verlag, Stuttgart.

Golubic S., G. Brent & T. le Campion. 1970. *Scanning Electron Microscopy of Endolithic Algae and Fungi using a Multipurpose Casting-Embedding Technique.* Lethaia 3: 203-209.

Hallbauer D.K. & H.M. Jahns, 1977. *Attack of lichens on quartzitic rock surfaces.* Lichenolog. 9: 119-122.

Henssen A. & H.M. Jahns, 1974. *Lichenes.* Thieme, Stuttgart.

Iscandar I.K. & J.K. Syers, 1971. *Solubility of Lichen Compounds in Water: Pedogenetic Implications.* Lichenolog. 5: 45-50.

Jahns H.J. & S. Ott., 1983. *Das Mikroklima dicht benachbarter Flechtenstandorte.* Flora 173: 183-222.

Jones D. & M.J. Wilson, 1986. *Biomineralisation in crustose lichens,* pp. 91-105. In: B.S.C. Leadbeater & R. Riding (ed.), Biomineralisation in Lower Plants and Animals. Carendon Press, Oxford.

Jones D., M.J. Wilson & W.J. McHardy, 1981. *Lichen weathering of rock-forming minerals: application of scanning electron microscopy and microprobe analysis.* J. Microscopy 124: 95-104.

Julien A.A., 1982. *On the Decay of Building Stone, part 1 and 2.* Trans. N.Y. Acad. Sc. 2: 67-79-120-138.

Krumbein W.E., 1966. *Zur Frage der Gesteinsverwitterung (über geochemische und mikrobiologische Bereiche der exogenen Dynamik).* Dissertation, Würzburg.

Krumbein W.E., 1969. *Über den Einfluss von Mikroorganismen auf die Bausteinverwitterung - eine ökologische Studie.* Deut. Kunst Denkmalpflege 31: 54-71.

Krumbein W.E. & C.E. Schönborn-Krumbein, 1987. *Biogene Bauschäden I. Anamnese, Diagnose und Therapie in Bautenschutz und Denkmalpflege.* Bautenschutz/Bausanierung 10: 14-23.

Krumbein W.E. & W.E. Schönborn-Krubein, 1987. *Biogene Bauschäden II. Anamnese, Diagnose und Therapie in Bautenschutz und Denkmalpflege.* Bautenschutz/Bausanierung 10: 110-117.

Ried A., 1960. *Stoffwechsel und Verbreitungsgrenze von Flechten. II. Wasser un Assimilationshaushalt. Entquellungs und Submersionsresistenz von Krustenflechten benachbarter Standorte.* Flora 149: 345-385.

Schade A., 1970. *Über Herkuft und Vorkommen der Calciumoxalate-Exkrete in kortikolen Parmeliaceen.* Nova Hedwigia 19: 159-187.

Schatz A., 1962. *Pedogenic (Soil Forming) Activity of Lichen Acids.* Naturwissen. 49: 518-519.

Schatz A., 1963. *Soil Microorganisms and Soil Chelation. The Pedogenic Action of Lichens and Lichen Acids.* Agric. Food Chem. 11. 112-118.

Schneider J., 1973. *Biologische and anorganische Faktoren beim Abbau einer Kalkküste*, vol. 1. Habilitationsschrift.

Smith A.L., 1921. *Lichens.* Cambridge University Press, Cambridge.

Spurr A.R., 1969. *A Low-Viscosity Epoxy Resin Embedding Medium for Electron Microscopy.* J. Ulstrastruct. Res. 26: 31-43.

Syers J.K., 1969. *Chelating Ability of Fumarprotecetraric Acid and Parmelia conspersa.* Plant Soil 31: 205-208.

Syers J.K., A.C. Birnie & B.B. Mitchell. 1967. *The calcium oxalate content of some lichens growing on limestone.* Lichenolog. 3: 409-414.

Syers J.K. & I.K. Iscandar, 1973. *Pedogenetic Significance of Lichens,* pp. 225-248. In: V. Amadjian, & M.E. Hale (ed.), The Lichens. Academic Press, London.

Torraca G., 1980. *Draft glossary for the description of macroscopic alteration in stone.*

Williams M.E. & E.D. Rudolph, 1974. *The Role of Lichens and Associated Fungi in the Chemical Weathering of Rock,* Mycologia 66: 648-660.

Zopf W., 1907. *Die Flechtenstoffe in chemischer, botanischer, pharmakologischer un technischer Beziehung.* Fischer, Jena.

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MICROSCOPICAL INVESTIGATION ON A MARBLE ENCRUSTING LICHEN

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Keywords: Lichens, Monuments, Marble, Optical and Electron Scanning Microscopy.

Abstract: The wheathering ability of *Aspicilia contorta* thalli with respect to their substrate, a marble tombstone, was studied by conventional, fluorescence, polarized and electron scanning microscopy. Our observations can help to visualize the mechanical fracturing and some product of the lichen metabolism which can affect the mechanical and chemical stability of the substrate.

Introduction

The effects caused by lichen colonization on lithic surfaces often give rise to serious problems of preservation for works holding an artistic and historical interest (Nimis et al. 1987).

This happens whenever, owing to the lichen covering, deterioration, chromatic alterations and loss of detail occur on the stonework.

The biodeterioration of the rock materials achieved by lichens results from physical and chemical processes (Syers & Iskandar 1973, Jones & Wilson 1985, Seaward 1988). The physical ones are erosion and breaking of the superficial layers in relation to hyphal adhesion and penetration between the particles of the substrate. That's because of the expansion and shrinking movements due to the variable hydration conditions of the thallus. The chemical ones, on the contrary, concern the solubilization and chelation processes carried out,in the formation of metallic complexes, by some metabolic products and other substances characteristic of the chemistry of the lichen thallus.

This investigation, based on the use of some methods of microscopical observation in the study of the relationships between an epilitic lichen and its substrate, is the first approach by the authors in the field of biodeterioration by lichens.

The authors hope to contribute to the definition of basic methods to study the physical-chemical changes due to the colonization of lichens on lithic substrates.

Materials and methods

Thalli of *Aspicilia contorta* (Hoffm.) Krempelh. were used in our microscopical investigations.

A few samples are preserved in the author's personal herbaria, a sample is in the lichenological herbarium of the University of Trieste (TSB, Herb. Nimis).

The lichen was growing on a fragment of a white marble of Carrara tombstone found in the graveyard of Semorile (Genoa), colonized mainly by the considered species.

Different procedures of preparation of the material were carried out according to the different kinds of microscopical observation.

1.1 - Small pieces of marble, colonized by the lichen, were obtained by a stone chisel impacting on the unbound block laid on the sand. These fragments were placed in diluted HCl (0.1-0.2 N) according to Fry's (1922) modified method till the $CaCO_3$ was removed (3-4 hours). The material was rinsed in water, then placed in phosphate buffer pH 6.8 0.01 M for 2 hours and subsequently fixed in FAA (formalin-ethanol 60%- acetic acid) (Sass 1958) for 24 hours.

After washing in buffer and after dehydration in an ethanol series, samples were embeded in JB4 water-soluble resin (Polyscience Inc.) (Brinn & Pickett 1979) in BEEM capsules (Polyscience Inc.). Sections 2.5 μm thick were cut with a glass knife on a Reichert OM2 microtome.

The following histochemical reactions were carried out on sections:

1.2 - Toluidine Blue 0 (TBO) 0.5% in water for 2 minutes as a general stain (O'Brien & McCully 1981).

1.3 - Toluidine Blue 0 (TBO) 0.5% in acetate buffer 0.05 M pH 4.4 as a metachromatic stain for polyanions (to demonstrate metachromasia of acid polysaccharides (Pearse 1985).

1.4 Periodic acid - Schiff reaction (PAS) for general localization of insoluble polysaccharides (Pearse 1985).

1.5 Alcian Blue 8GX 1% in acetic acid 3% at pH 2.5 for 30 minutes for the localization of acid polysaccharides (Lev & Spicer 1964).

2.1 - Small pieces of thallus were detached from the substrate by a sharp chisel, then treated according to Yasue method (1969). Samples were placed in acetic acid 5% for 30 min. to remove calcium carbonate and the possible presence of calcium sulphate and phosphate; they were then transferred in $AgNO_3$ 5% for 15 min. and later rinsed in a saturated solution of rubeanic acid (ditio-oxamide) in ethanol 70% including 2 drops of NH_4OH 25% for 1 min.

Through this procedure the crystals of calcium oxalate, insoluble in acetic acid, showed themselves as a dark-brown precipitate when observed with light conventional microscopy.

2.2 - After digestion with acetic acid 5%, some of the samples were dehydrated and embedded in JB4 as described above. Semithin sections, stained with aqueous TBO, were observed by light conventional microscopy supplied with orientative polarization (see further).

Another series of observations were carried out on samples freely sectioned on the substrate. This in order to visualize the interactions between the lichen and its substrate by means of two procedures.

3.1 - Marble sections about 1 mm thick carrying lichen, were obtained by a sharp woodwork chisel, struck by a hammer, impacting on the unbound block. The stroke on the block was thrown perpendiculary to its borders: in this way it detached the small above-mentioned sections, used in the different observations.

3.2 - A parallel series of observations were carried out on sections obtained by the chisel impacting parallely with the surface of the marble and very little below it.

This method allowed to obtain thin marble chips carrying small pieces of lichen, suitable for the superficial view of the thallus.

The samples obtained in this way were employed in the following conditions:
a) observed with orientative polarization
b) observed with fluorescent microscopy
c) observed with scanning electron microscopy

The above cited observations (a) and (b) were carried out by a Leitz Dialux 22 EB microscope.

Particularly in the observations (a) an apparatus for the orientative polarization was added to the microscope, consisting of an analyzer suitable for its interposition between the eye-piece and the lens and of a rotating polarizer placed before che condenser.

In the observations (b) a Ploem-Opak epi-fluorescent apparatus was added to the microscope together with a Hg HBO vapour lamp (50 W) and with two Leitz filter-systems. The former (H2) determines the blue-violet incident light between 390-490 nm of wavelenght, the latter (A) determines a ultraviolet incident light between 340-380 nm of wavelenght.

In a microscope equipped by epi-illumination the thickness of the examined samples is not very important; this permitted us to employ the marble chips.

For the SEM observations the samples were directly coated 200-220 Å in thickness with gold in a Sputtering Agar Aids and observed with a Cambridge Stereoscan 250 MK2 at an acceleration voltage of 20 Kv.

Results and discussion

Aspicilia contorta is an epilithic areolate lichen which forms a dense covering on the examined marble surface. The tombstone is situated 60 cm above the ground, facing South and having a sub-horizontal lying. Fig. 1, a SEM micrograph obtained with 3-i procedure, shows the substrate underlying the lichen. In SEM observations the marble appears like a rock of granular close structure, made by crystal aggregates of small rhombohedral particles of calcite (grains), here about 200 μm in thickness. They are closely connected without a specific link, owing to interaction forces rising from the typology of formation, which hold them together (Mannoni & Mannoni 1978). In the same illustration some detachments among the

grains are visible, presumably an artefact caused in this case by the cutting technique. According to Manganelli del Fà & Lazzarini (1986) every outer force acting on the rock can affect the stability of the granoblastic structure, producing microfissures. In other words according to the above mentioned authors, already during the excavation of the blocks, the material might undergo stresses becoming still bigger and bigger during the realization of the manufacture. In consequence of this some superficial porosities in the marble may occur. Moreover, because of the anysothropic features in relation to the expansion coefficient of calcite crystals, some tensions inside the rock may take place when directly exposed to the sun light. Such tensions would lead to disaggregation of the grains, together with clear processes of polygonal cracks and superficial crumbling on the exposed areas of the marble (Manganelli del Fà % Lazzarini 1986). In this way the above mentioned events should promote the establishment of various epilithic organisms and their following penetration.

The micrograph 2, a magnification of the foregoing one, shows a bundle of hyphae of *Aspicilia contorta* creeping along the face of a calcite grain, once adhesion surface of another grain.

The lichen hyphae should have penetrated through a pre-existent porosity, reaching about 400 μm in depth, as it's deducible from fig. 1.

We can suppose that the alternate hydration conditions and the lichen growth increase the detachment of the grain.

Hyphal penetration is still visible at 1 mm in depth in fig. 3, another magnificant of fig. 1, showing other interesting effects due to the lichen presence. The central part of the micrograph shows the above examined aspect, the magnification of its upper side (figs. 4, 5, 6) bears evidence of clear and deep incisures on the surface of the calcite crystals, looking like the impression leaved by the lodgings of the hyphal ramifications. Such incisures seem to testify a superficial former corrosion of the grains, appearing as distinctive "furrowings" of the mineral surface.

In our case the SEM observations seem to show that the hyphal ramifications don't penetrate the hard calcite crystals, but eroding them superficially, they go round them, creeping in depth afterwards, exploiting and increasing detachments of the grains.

Fig. 1 - 6: Scanning electron micrographs.

Fig. 1 - Fragment of marble of granoblastic structure carrying *Aspicilia contorta* (arrow). X 70.

Fig. 2 - Along the surface of a calcite grain a bundle of deeply penetrating hyphae, is visible. X 700.

Fig. 3 - At 1 mm in depth (compare with fig. 1), bundles of hyphae and their marks, looking like "furrowings" along the faces of the calcite grains, are visible. X 200.

Fig. 4 - 6: Various aspects of the grain surfaces colonized by the lichen thallus. Clear incisures of the mineral surface and the hyphal ramifications are visible. Fig. 4: X 800; fig. 5: X 500; fig. 6: X 1200.

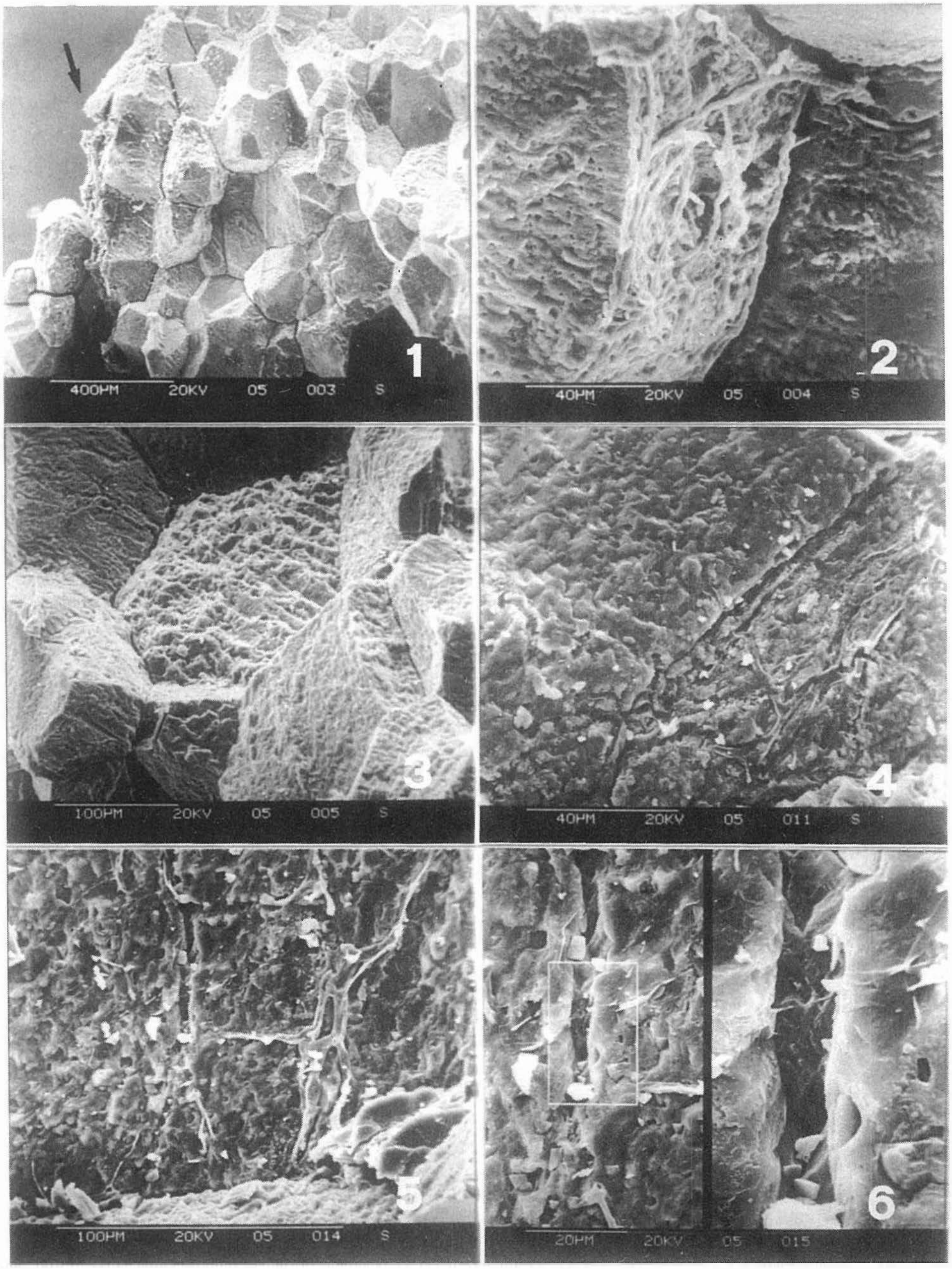

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Fig. 7 shows a semithin section of the upper portion of an areola of *Aspicilia contorta* after removal of the substrate (1.1), stained with TBO (1.3) at pH 4.4.

In this conditions several different polyanions (polycarboxylic acid, polysulphates and polyphospates) carry a negative charge and give a metachromatic reaction, staining magenta-red with TBO.

The remaining portions of the thallus stain orthochromatically (blue); the outer part of the cortex and the medulla stain metachromatically.

The positive PAS (1.4) and Alcian Blue (1.5), here not shown, confirm this fact giving evidence of the mucopolysaccharidic nature (carboxylated polysaccharides) of the substance responsible for the metachromatic staining with TBO.

This type of molecule is capable of linking water in amounts directly related to the intensity of the available negative charges (Modenesi & Vanzo 1986).

Mucopolysaccharidic substances can contribute to thallus hydration, delaying drying and preventing excessive water loss. Fig. 8 shows the lower part of the areola: in direct contact with the substrate the hypothallus in visible. It is made up of a network of hyphal bundles, not penetrating the rock in this area.

On the contrary, two other illustrations (figs. 9, 10) show that thick bundles of hyphae creep in depth, just where this penetration is possible, probably because of the pre-existent superficial disgregations of the grains.

In this case the observations carried out with SEM are confirmed. It's opportune to report the presence, at 400-500 μ in depth, of clusters of algae which have been brought here by the penetrating bundles of hyphae (figs. 10, 11).

This has been reported as a common feature in some epilithic lichens growing on calcareous rocks (Fry 1922). This fact testifies, according to us, the good hydration conditions and the sufficient lighting in depth. Marble is a translucent rock: light passes through a 25 mm in thick section of white marble of Carrara (Mannoni & Mannoni 1978).

Inside the substrate the hyphae constituting the bundles sometimes take a globular appearance (fig. 12), forming dense clusters of spheroidal, thin walled cells.

These formations (Bachmann 1919, Fry 1922, Kushnir et al 1978) in epi- and endolithic lichens mostly on calcareous substrates, are known as oil hyphae containg triacylglycerol as the predominant lipid component (Kushnir et al. 1978).

Following the 1.1 procedure, the dehydration in an ethanol series and the em-

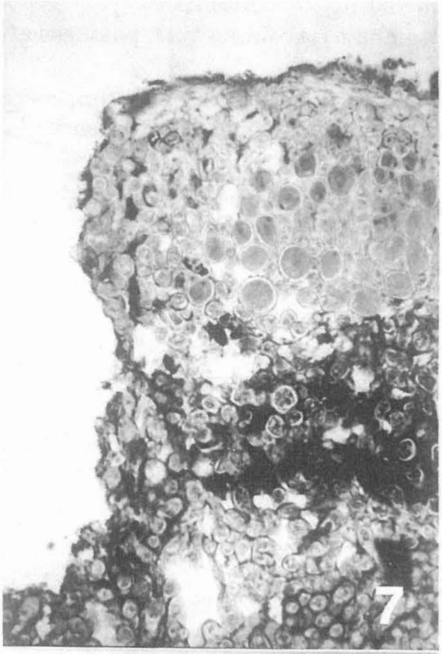
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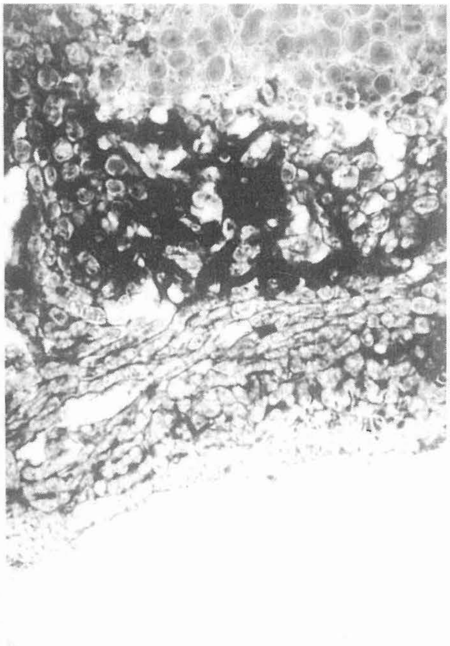
Fig. 7 - 12: Semi-thin cross sections of the thallus of *A. contorta* after removal of calcium carbonate by hydrochloric acid. TBO.

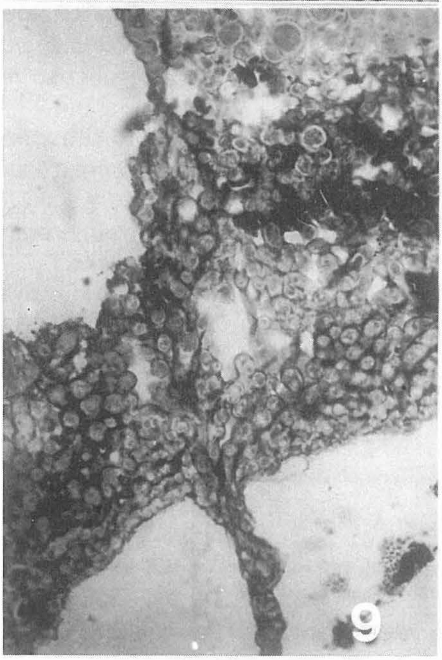
Fig. 7 - Upper portion of an areole. The medulla and the thin outer portion of the cortex stain metachromatically. X 500.

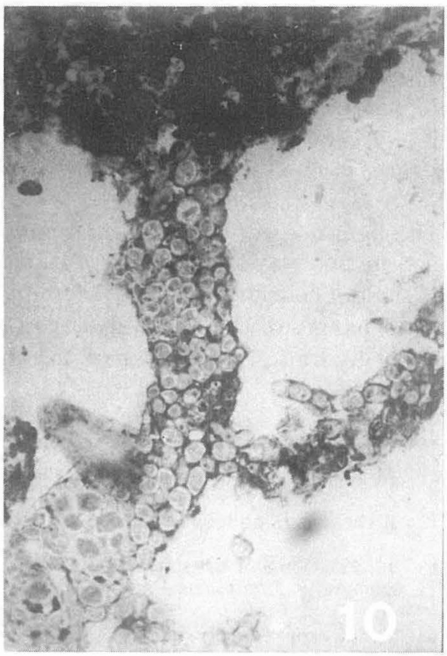
Fig. 8 - Lower part of an areole. Note the network of the bundles of hyphae, constituting the hypothallus, directly in contact with the substrate (here removed). X 500.

Fig. 9 - 10: Some strong bundles of hyphae leave the hypothallus, they deeply creep into the substrate exploiting its porosities. X 500.


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bedding in resin have completely removed the lipidic contents.

The histochemical evidence may be obtained by avoiding such passages after digestion with HCl (1.6).

The content, little oil drops, is displayed by staining with benzopyren, specific and very sensitive to lipids which stain bluish in fluorescence when observed under UV light (A filter) (fig. 13).

Using such stain the formations of oil hyphae appear to be plentiful and diffused in the whole soft hyphal network penetrating marble through its several porosities (fig. 14). Beside the apothecia (fig. 15), in accordance with the observations of Fry (1922), a lot of such formations are visible; this may be in relation to the zones of high metabolism.

According to other authors, Fry (1922) suggested that the lipid formed a storage of waste product in relation the adverse environment conditions, such as the scarcity of nitrogen and the excess of calcium carbonate.

Kushnir et al. (1978), on the basis of the observation that isolated mycobionts of endolithic lichens retained their ability to produce and accumulate unusually large quantities of lipids under optimal growth conditions, think this feature as to be due to the genetics of the fungus, but they consider still enigmatic its display in epi- endolithic lichens. Other authors (Dertien et al 1977) suggest that oil is a possible source of endogenous water or that it represents a storage material and a metabolic fuel (Sorokin 1967).

Apart from the functional meaning of the oil hyphae, it seems reasonable to point out their massive presence in the suprficial zone of the marble colonized by *Aspicilia contorta*. The role played by the lipidic material with respect to rock biodeterioration is unknown.

Fig. 16 shows the thalline surface of *A. contorta* still binded to the marble substrate, viewed with light microscopy equipped with orientative polarization (3.2).

The light doesn't pass the thick areolate thallus, but it does through marble cracks, in this way drawing the outlines of the thalline compartiments.

It's under consideration the possibility of using this type of observations to follow the changes of the size and of the borderline of the areoles in relation to the different hydration conditions of the thallus.

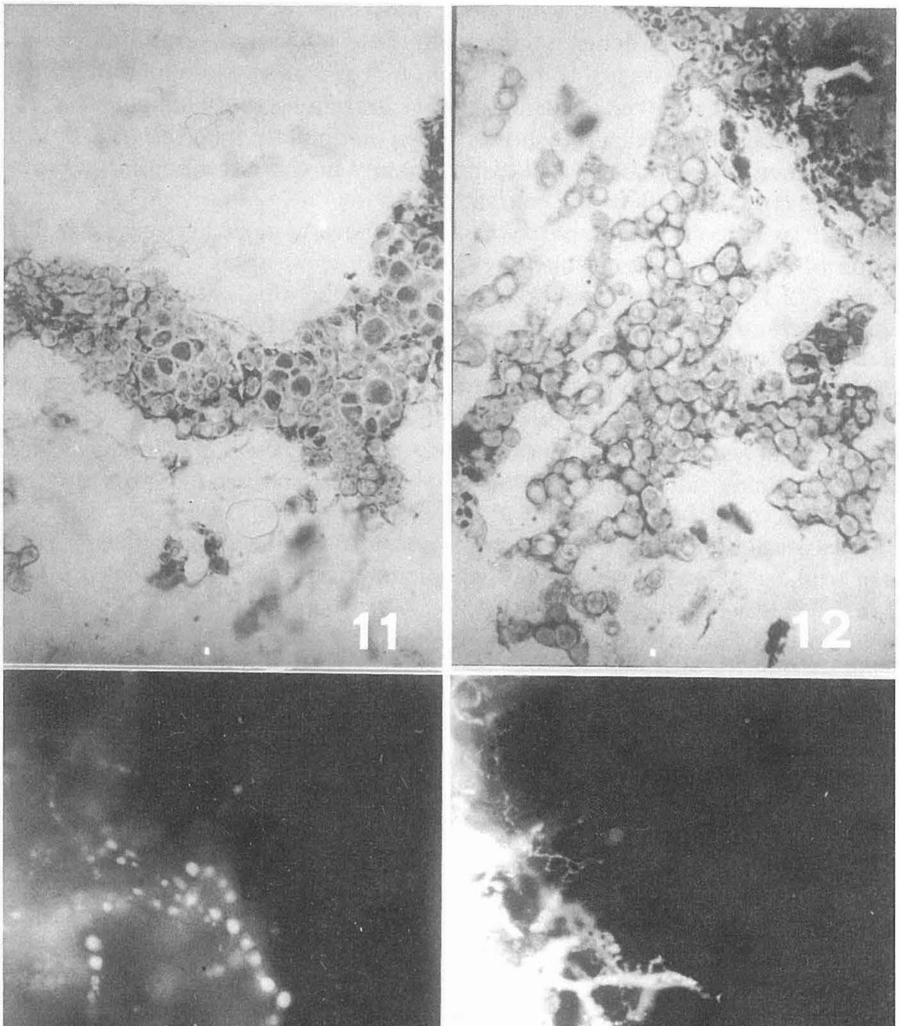
Fig. 11 - At 400-500 μm in depth inside the substrate some clusters of algae are visible. X 500.

Fig. 12 - A cluster of "oil hyphae" inside the substrate. X 500.

Fig. 13 - 15: Fragments of the thallus after digestion of calcium carbonate by HCl stained with benzophyrene. Fluorescence microscopy, UV light.

Fig. 13 - The oil drops contained in the oil hyphae are visible on account of their bluish UV fluorescence after staining with benzophyrene. X 500.

Fig. 14 - All the fine hyphal weaving, penetrating the marble, are rich in oil storages. X 100.


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In fact according to Malinowski (1911) the areolate structure is an adaptation peculiar to the epilithic lichens against alternate hydration situations.

The figs. 18, 19, 20 regard thin sections (2.2) of material in which the calcium carbonate has been removed by acetic acid 5%, and stained with aqueous TBO (1.2).

The orientative polarization shows, when completely inserted (fig. 20), that some birefractive crystals are still visible mainly in the lateral epilithic parts of the areoles (figs. 18 and 19 for comparison).

Fig. 21, with polarization partly inserted, shows a more general view of the location of crystals in the areoles.

Fig. 17 (2.1) shows the appearance of a thalline areole treated with acetic acid 5% and then stained with the Yasue method (1969) for the localization of calcium oxalate. This appears as a brown-black precipitate.

The upper view of the areole with the oxalate precipitate placed as a ring, confirms the observations carried out with orientative polarization.

Oxalic acid seems to be an important agent of weathering of rocks (Jones et al. 1980), forming salts whose cations depend on the nature of the lithic matrix colonized by the lichen (Wilson et al. 1980).

Ascaso et al.(1882) were able to point out that dissolution of calcite by secretion of oxalic acid led to precipitation of calcium oxalate in *Caloplaca callopisma* and other calcicolous lichens.

Our observations visualize this phenomenon in *A. contorta* showing the localization of the oxalate.

Sections obtained with the 3.1 procedure have been observed by fluorescence microscopy.

Fig. 22 shows one of these samples observed under violet-blue light (H2 filter). In the picture are visible the cross sections of an areole and of a lecanorine apothecium, in which the algae, fluorescent in red because of the chlorophyll a, climb up the thalline edge.

The medullary hyphae, beneath the apothecium and in the near areole, penetrate into the marble and have a yellowish fluorescence.

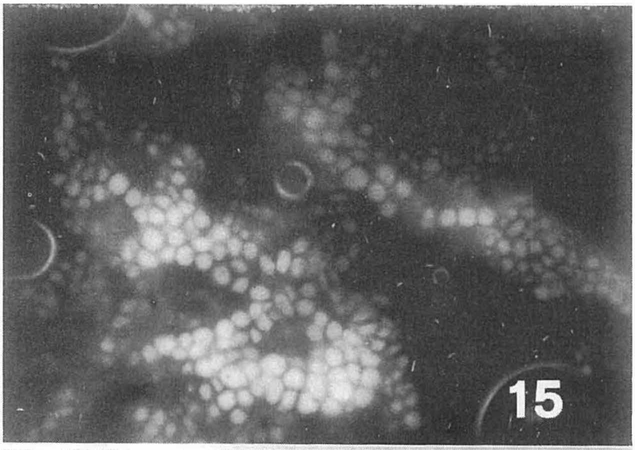
The cortex is not visible by means of this type of observation, but when the sections were observed under ultraviolet light (A filter) the algal layer is hardly visible, the medulla and the cortex appear bluish fluorescent (fig. 23). Fig. 24 shows such bluish fluorescence by a greater magnification, this picture may be

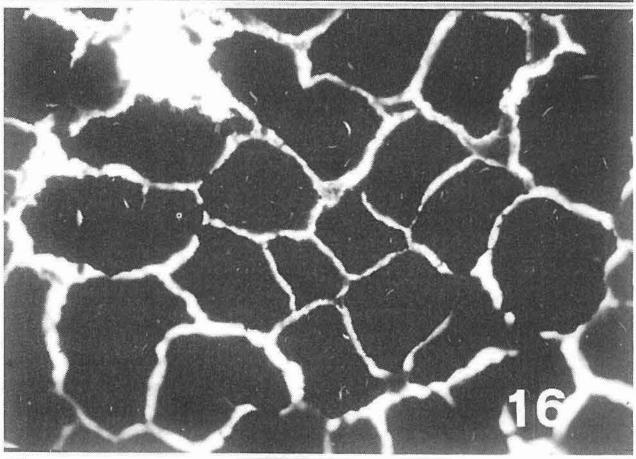
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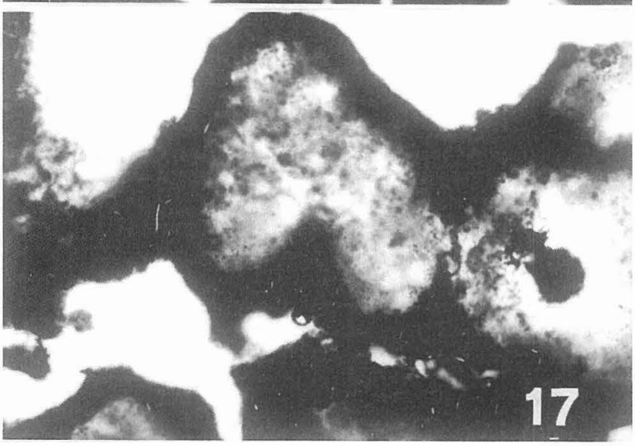
Fig. 15 - The oil storages are mainly placed beneath the apothecia. X 500.

Fig. 16 - Upper view of the thallus of *A. contorta* still binded to the marble, observed with orientative polarization. The light doesn't pass through the thick thalline areoles, looking dark, while it does through the fissures where the thin hypothallus occurs. X 100.

Fig. 17 - Upper view of a thalline areole after digestion of calcium carbonate by acetic acid and then treated according to Yasue (1969) method. The calcium oxalate precipitates stain dark-brown. X 100.


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compared with a section obtained by the same procedure (3.1), but observed in orientative polarization (fig. 25). In the cortex a deposit of birefractive crystalline material is clearly visible, corresponding to the material responsible of the bluish fluorescence of the cortex in UV.

The localization of this UV fluorescent material may be observed one more time following the 3.2 procedure. Examining the thallus with fluorescence microscopy, a bluish fluorescent deposit becomes visible, widespread on the cortical surface of the areoles and absent in the crack. Such deposit can be removed by a previous immersion in acetone for a few minutes.

Some investigations (TLC analysis, data not reported) carried out about the nature of this substance and informations from the literature (Culberson 1969, 1970; Culberson et al. 1977) led us to exclude any connection between the substance observed by fluorescence microscopy and the lichen substances known in *A. contorta*. This substance, moreover, though is soluble in acetone as the lichen substances, unlike these ones appears to be strongly water soluble.

In fact observing figs. 27 and 28 we can note, as well as it's visible with fluorescence microscopy, the immediate removal of the UV fluorescent cortical substance due to a water drop (fig. 26) added to a section initially examined in dry conditions (fig. 27).

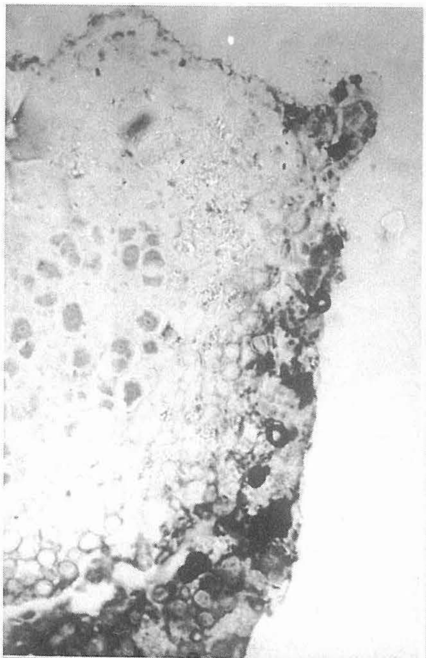
Some lichen substances show a very low water solubility, about 5 to 57 mg/l (Iskandar & Syers 1972); however this is sufficient, owing to the presence of polar groups, to justify their capability to form metallic complexes with the cations constituting the mineral surfaces (Syers & Iskandar 1973).

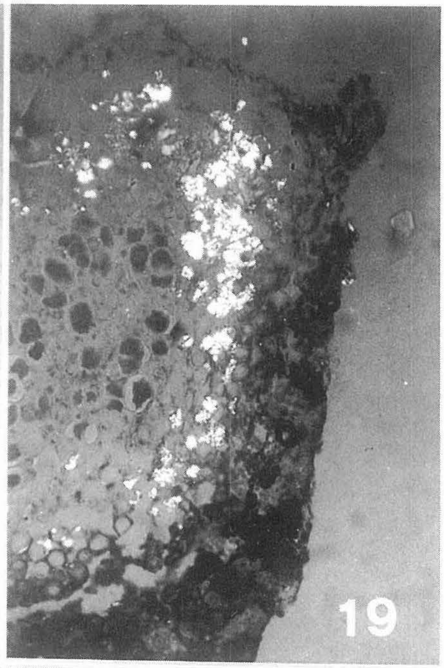
At present we are investigating the nature of the UV fluorescent substance, trying to characterize it and to determine its possible capability to complex metal cations of the substrate.

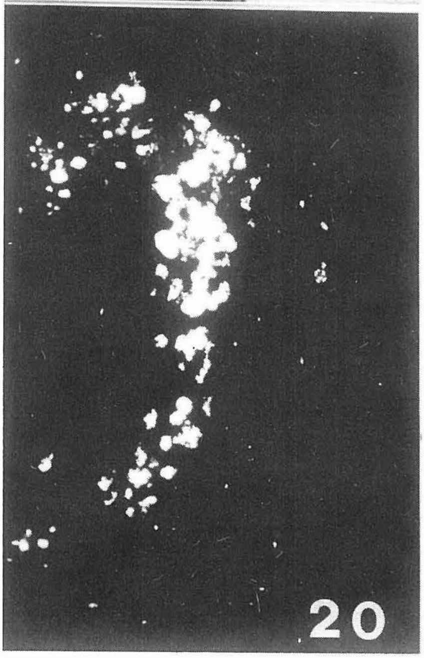
Fig. 18 - 21: Cross sections of a thalline areole after removal of calcium carbonate by acetic acid. Observations with the orientative polarization.

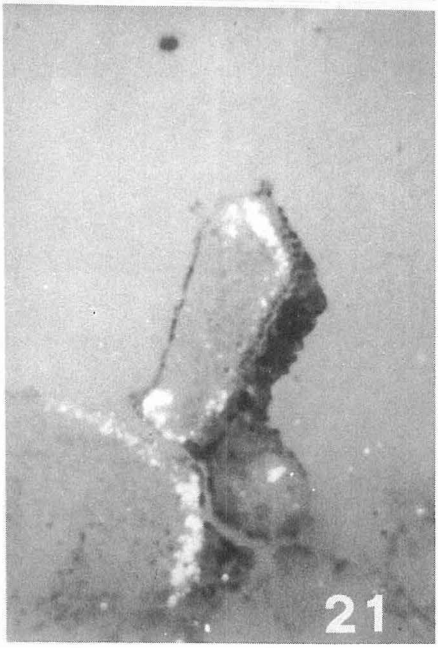
Fig. 18 - 20: Series of micrographs showing the appearance of the birefractive crystals of calcium oxalate along the lateral portions of an areole. Polarization excluded (fig. 18), partly inserted (fig. 19), entirely inserted (fig. 20). X 500.

Fig. 21 - General view of the thalline areoles containing the birefractive crystals of calcium oxalate. Polarization partly inserted. X 100.




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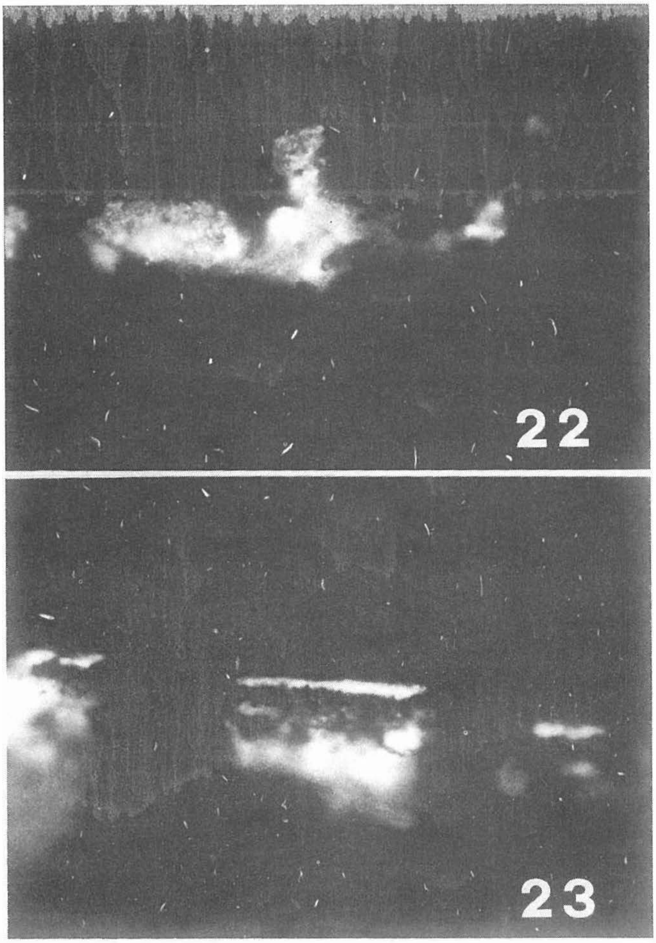


Fig. 22 - 24, 26 - 28: "Free-hand" sections of *A. contorta* thalli still binded to the marble. Fluorescence microscopy.

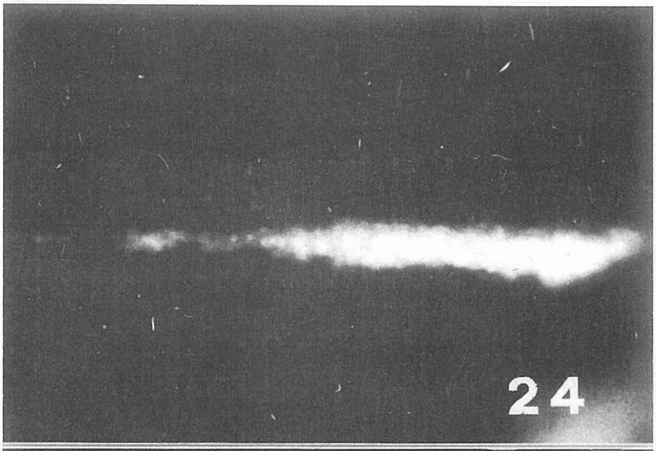
Fig. 22 - Cross section of an areole and an apothecium. Observation under violet-blue exciting light. X 100.

Fig. 23 - Cross sections of an areole observed under UV exciting light. Note the intensely fluorescent (bluish) strip at the cortical level. X 100.

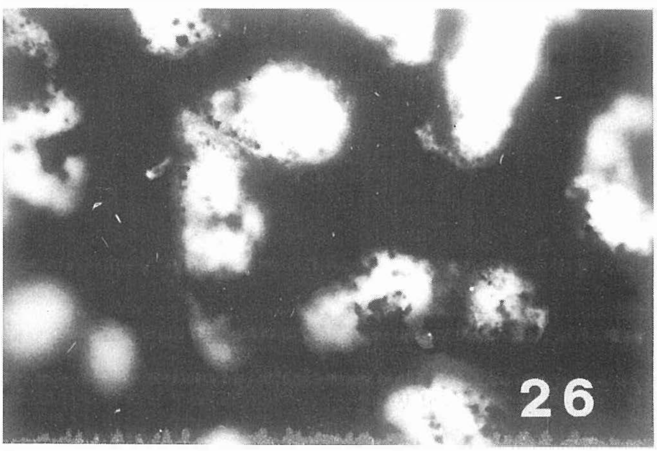
Fig. 24 - Magnification of the preceding one showing the fluorescent strip at the cortical level. X 500.

Fig. 25 - Cross sections of a thallilne areole observed in polarized light. In correspondance of the cortex a shining band is visible due to the occurrence of birefractive crystals. X 100.

Fig. 26 - Upper view of the thallus observed under UV exciting light. A bluish fluorescence occurs upon every areole. X 100.


24


25


26

Conclusion

The techniques of observation with the optical microscopy provide a valuable tool of investigation because of their versatility and suitabillity to the different conditions of study.

The use of resins for the preparation of samples and the use of modern methods of histochemical observations make easier the possibility of carrying out careful structural and clear morphofunctional studies, integrated by parallel observations under polarized light and with epifluorescence microscopy, as it's shown by our work.

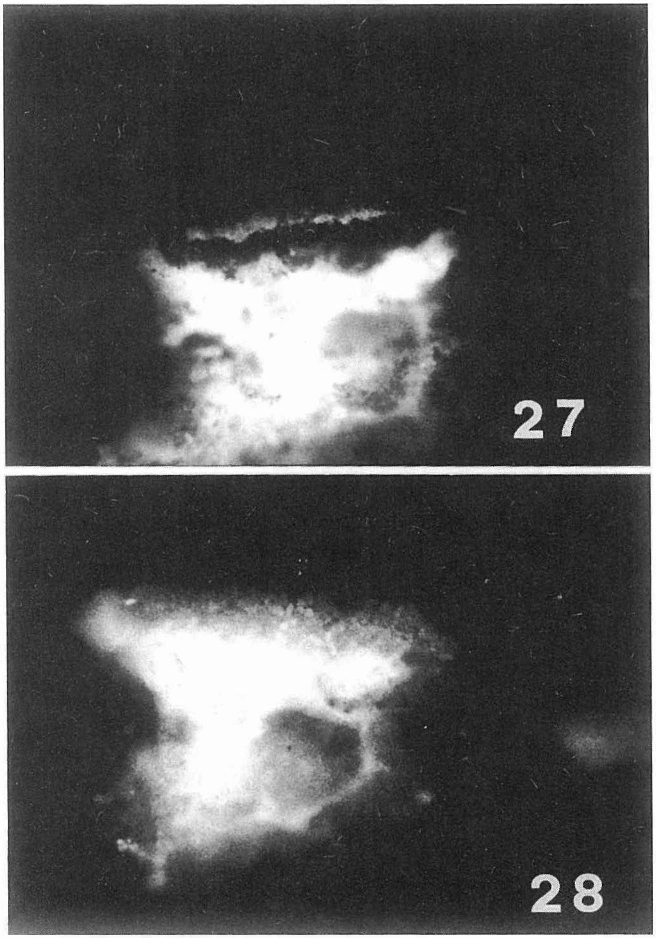
The methods of microscopical investigation constitute a useful background which can contribute, together with other methods of study, to the knowledge of the complex relationships between a lichen and its substrate, through the direct visualization of the effects.

When the lithic matrix colonized by the lichen holds such interest that it warrants its preservation the direct visualization of physical and chemical alterations may contribute to the determination of precise preservative actions.

This in accordance with the type of the relations observed, depending on the nature of the substrate and on the lichen species.

Fig. 27 - Cross section of a thalline areole observed under UV exciting light. The sample is laid on the slide in dry conditions. X 100.

Fig. 28 - The same preceding picture observed after the sample was wetted directly under the lens. Note that the bluish fluorescent strip once distinguishable in the cortex, now it's no longer visible. X 100.



References

Ascaso C., Galvan J. & Rodriguez-Pascual C., 1982. *The wheathering of calcareous rocks by lichens.* Pedobiologia, 24: 219-229.

Bachmann E., 1919. *Der Thallus der Kalkflechten mit Chroolepis, Scitonema und Xanthocapsa-Gonidien.* Abh. Kaiserl. Leop.-Carol. Deutsch. Akad. Naturf. 105 (I). Halle.

Brinn N.T. & Pickett J.P., 1979. *Glycol methacrylate for routine special stains, histochemistry, enzyme histochemistry and immunohistochemistry.* J. Histochem., 2: 125-130.

Culberson C.F., 1969. *Chemical and Botanical Guide to Lichen Products.* Chapel Hill.

Culberson C.F., Culberson W.L. & Johnson A., 1977. *Second supplement to "Chemical and Botanical Guide to Lichen Products".* St. Louis.

Dertien B.K., De Kok L.J.& Kuiper P.J.C., 1977. *Lipid and fatty acid composition of tree-growing and terrestrial lichens.* Physiol. Plantarum, 40: 175-180.

Fry E.J., 1922. *Some types of endolithic limestone lichens.* Ann. Bot. (London), 36: 541-562.

Iskandar I.K. & Syers J.K., 1972. *Metal complex formation by lichen compound.* Journal Soil Science, 23: 255-265.

Jones D., Wilson M.J. & Tait J.M., 1980. *Wheathering of a basalt by Pertusaria corallina.* Lichenologist, 12: 277-289.

Jones D. & Wilson M.J., 1985. *Chemical activity of lichens on mineral surfaces. A review.* International Biodeterioration, 21: 99-104.

Kushnir E., Tietz A. & Galun M., 1978. *"Oil Hyphae" of endolithic lichens and their fatty acid composition.* Protoplasma, 97: 47-60.

Lev R. & Spicer S.S, 1964. *Specific staining of sulphate groups with alcian blue at low pH.* J. Histochem. Cytochem., 12: 309-329.

Malinowski E., 1911. *Sur la biologie et l'écologie des lichens épilithiques.* Bull. Acad. Sc. de Cracovie, sér. B, Sc. Nat. 349-390.

Manganelli del Fà C. & Lazzarini L., 1986. *Genesi, composizione e alterazione del marmo. In Restauro del Marmo, Opere e Problemi:* 54-48. OPD Restauro, Quaderni dell'Opificio delle Pietre Dure Firenze: Opus Libri.

Mannoni L. & Mannoni T., 1978. *Il Marmo, materia e cultura.* Genova: SAGEP.

Modenesi P. & Vanzo C., 1986. *The cortical surfaces in Parmelia saxatilis and P. caperata: a histochemical approach.* Lichenologist, 18: 329-338.

Nimis P.L., Monte M. & Tretiach M., 1987. *Flora e vegetazione lichenica di aree archeologiche del Lazio.* Studia Geobotanica, 7: 3-161.

O'Brien T.P. & McCully M.E., 1981. *The study of plant structure. Principles and selected methods.* Melbourne: Termacarphi.

Pearse A.G.E., 1985. *Histochemistry, theoretical and applied.* London: Churchill-Livingstone.

Sass J.S., 1958. *Botanical microtechnique.* Ames: Iowa State University Press.

Seaward M.R.D, 1988. *Lichen damage to ancient monuments: a case study.* Lichenologist 20: 291-295.

Sorokin H., 1967. *The spherosomes and the reserve fat in plant cell.* Amer. J. Bot., 54: 1008-1016.

Syers J.K. & Iskandar M.J., 1973. *Pedogenetic significance of lichens.* In *The Lichens* (V. Ahmadjan and M.E. Hale, eds.): 225-248. New York: Academic Press.

Wilson M.J., Jones D. & Russel J.D., 1980. *Glushinskite, a natural occurring magnesium oxalate.* Mineralogical Magazine, 48: 837-840.

Yasue T., 1969. *Histochemical identification of calcium oxalate.* Acta Histochem. Cytochem., 2: 83-95.

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STUDIA GEOBOTANICA
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COLONIZATION OF MOSAICS BY LICHENS: THE CASE STUDY OF ITALICA (SPAIN)

J. GARCIA-ROWE and C. SAIZ-JIMENEZ

Keywords: Lichens, Mosaics, Spain.

Abstract: A black and white mosaic of the Neptune's house, located in the 2nd century Roman city Italica, was investigated in order study the lichen colonization of tesserae and mortars. Different strategies were observed. They lead to colonization of mosaic in such an extent that lichens clothe the represented figures, masking and affecting the esthetic value of this work of art.

Introduction

Italica is a Roman city located near Sevilla. It was founded in 206 b.C. by the Roman general Scipio Africanus, after the battle of Ilipa (Second Punic War) and represents the settelement of the first Roman people on the Iberian peninsula and the beginning of a rapid romanization.

During the 2nd century a.C. Italica was favoured by donations, public buildings, city walls and a new area of sumptuous residential quarters, the nova urbs.

After the 4th century a.C. there was a gradual decline of the nova urbs until it was finally abandoned.

The official archeological excavations began during the 18th century, but it was during the middle of the 19th century and this century when they developed.

The excavated part of the city offers the visitors a panorama of wide avenues and houses with a considerable number of black and white and polychromatic mosaics. These mosaics are protected from visitors by barriers and, because they were not cleaned periodically, algae, lichens and mosses, among other organisms, have the chance of developing on the rock substrate.

In this paper, a black and a white mosaic have been selected, located in the so-called Neptune's house, for investigating the lichen colonization. This represents the simplest case in which only two types of rocks are involved. Polychromatic mosaics with an ample variety of rocks present a more complicate colonization pattern with many species of lichens. This will be studied in a further paper.

Material and methods

The studied mosaic is located in the Neptune's house and appers to belong to the remains of an extensive villa of about 7000 m^2. The house contains 8 *opus tesellatum* and 1 *opus fliginum* pavements.

The black and white mosaic represented a repetitive hexagonal figure in which a star and a six petaled flower are inserted. The pavement dimensions are 4.90x4.50 m^2 and belong to the 2nd century A.C. (Rodriguez Hidalgo, 1987).

The tessera composition is marble and the cubes of about 1 cm^2 were regularity cut, showing a smooth surface. In general the pavement is well preserved, although some cracks cross over the mosaic. The lost surface represents about 22%. The conservation history is unknown although 15-20 years ago the tesserae were removed and included in a new support.

The most characteristic fact is the extensive lichen development on both black and white tesserae as well as on the mortar.

Results and discussion

Lichens are conspicuous pioneers on rock and initiate stages of succession. Mosaics are considered as a stable rocky substrate and the lichen communities have the chance of developing to maturity over long periods of time.

It is generally considered that a period of some years must pass before lichens establish themselves on new substrates (Seaward, 1977). The mosaics were excavated since 1919 and particularly between 1924 and 1932, although a few Italica's houses were excavated in the early seventies. During the elapsed time no regular cleaning to ensure removal of dust or organic matter deposition was done.

Different colonization strategies have been observed in the lichens colonizing the mosaics. They can be summarized as follows:

- Direct colonization on tesserae (Figure 1). The lichens are adapted to pioneer growth on bare rock and have the ability to adhere, penetrate and digest minerals. In general, the attack is both mechanical and chemical. Mechanically, the penetrating hyphae, by alternative swelling when wet and contracting when dry produce cracking. Chemical activities are represented by the synthesis and excretion of organic acids (e.g. oxalic acid) and lichenic acids (Syers et al., 1967; Iskandar and Syers, 1972).

This type of attach on the tesserae is exemplified, among others, by *Caloplaca* sp., a saxicolous, nitrophilous lichen with a typical crustose thallus without lower cortex (Brighman and Nicholson, 1977).

- Colonization of mortars and subsequent invasion of tesserae (Figure 2). In this case, the lichens have not enough ability for colonizing bare rocks due to a less pronunced pioneering character. Therefore, they thrive on a weathered substrate, the mortar, more adapted to support colonization. Pore size, desintegration and dissolution of minerals, a richer substrate and favourable water relations, all contribute to facilitate the exploitation of this environment. Lichens such as *Lecidea*

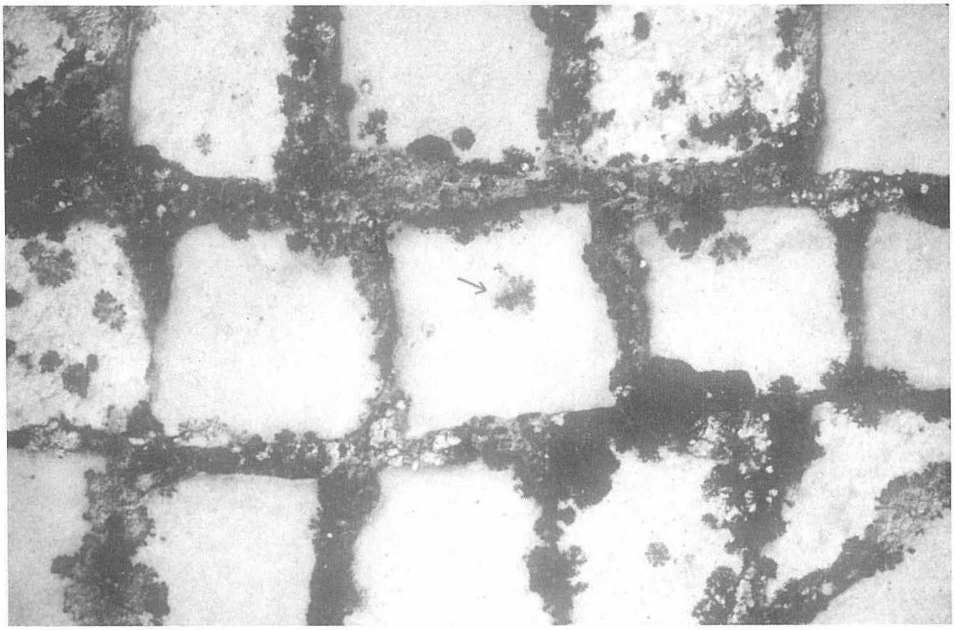


Fig. 1 - Direct colonization on tesserae. *Caloplaca* sp.

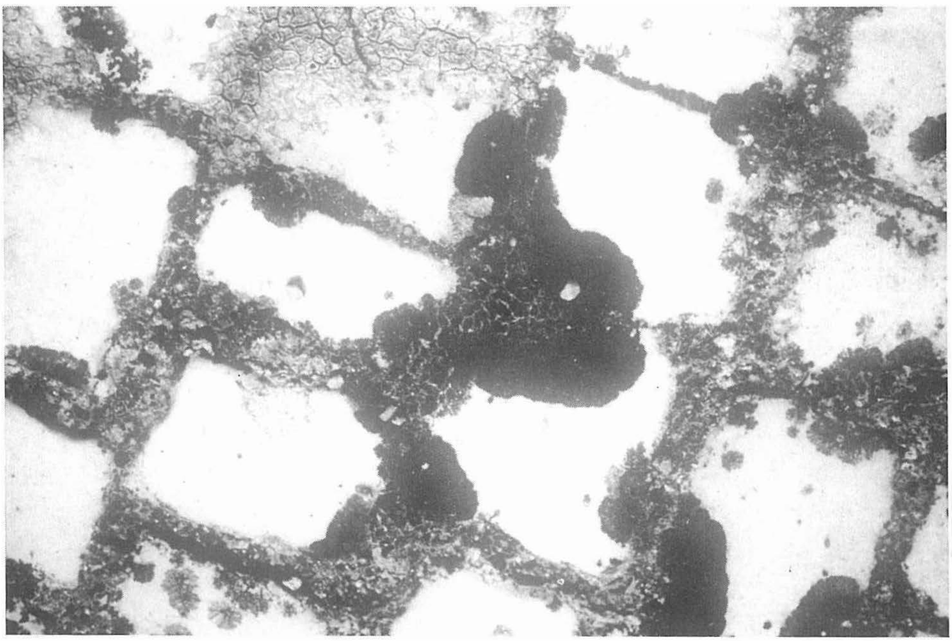


Fig. 2 - Colonization of mortar and subsequent invasion of tesserae. *Lecidea* sp.

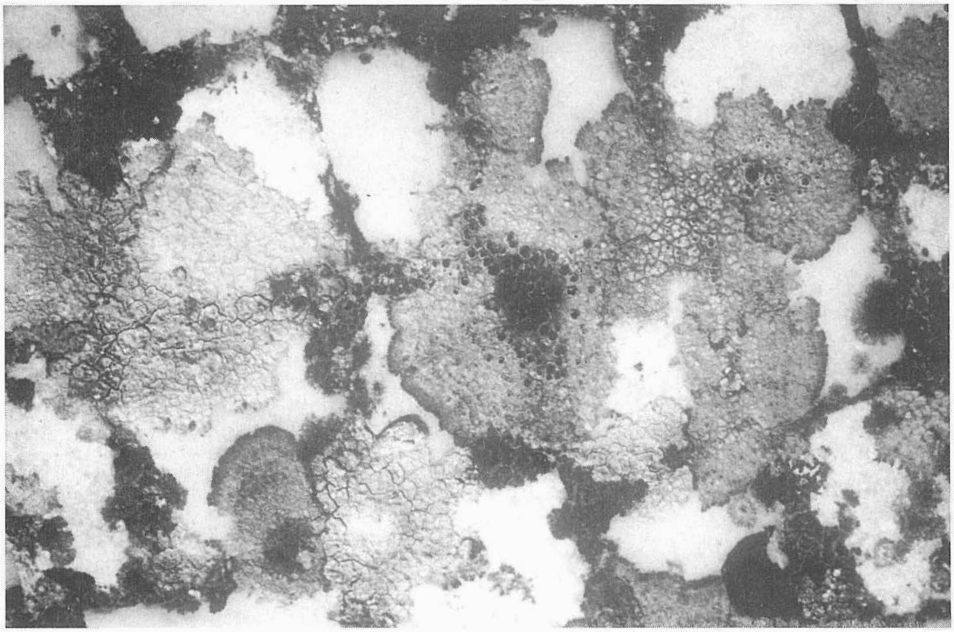


Fig. 3 - Colonization of mortar and invasion of tesserae. *Aspicilia* gr. *radiosa*.

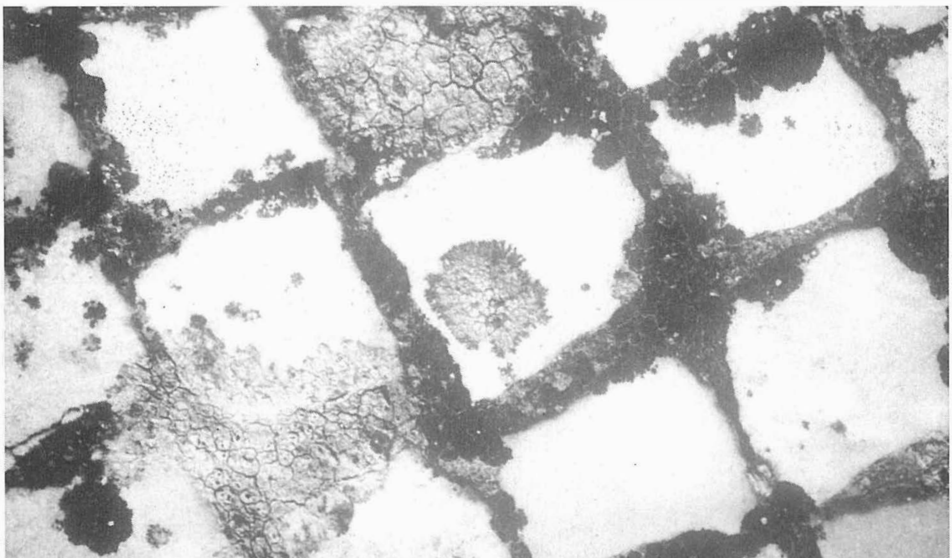


Fig. 4 - Non-specific colonization. *Aspicilia hoffmannii*.

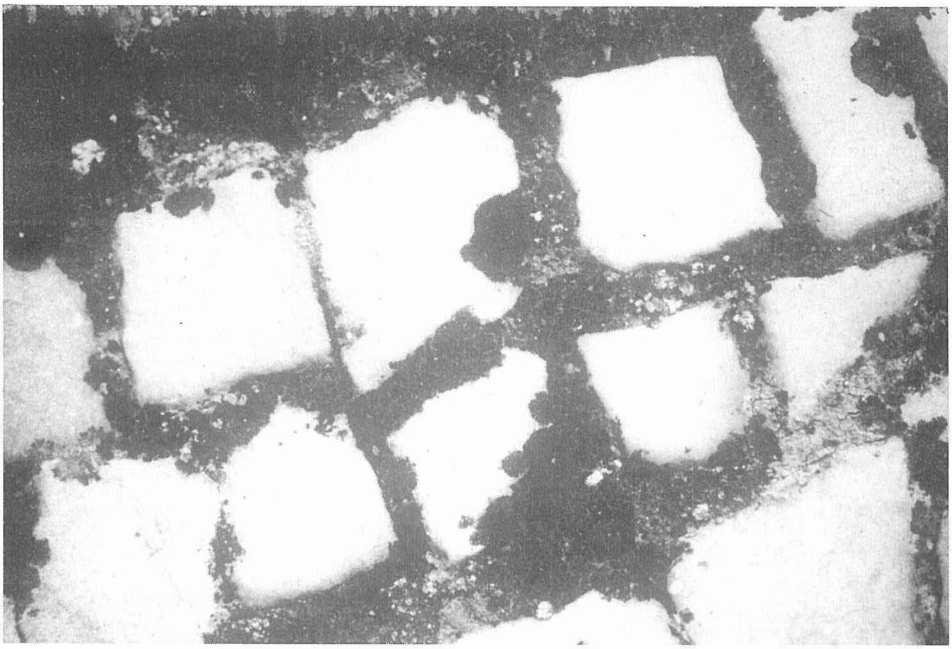


Fig. 5 - Lichenicolous species. *Caloplaca* sp.

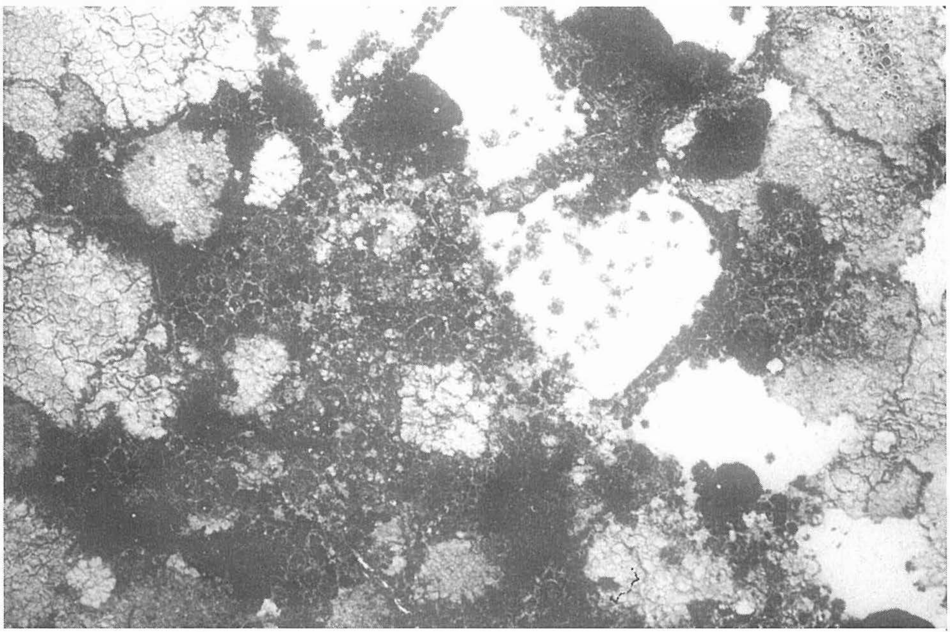


Fig. 6 - Stage of mosaic colonization leading to clothing of tesserae.

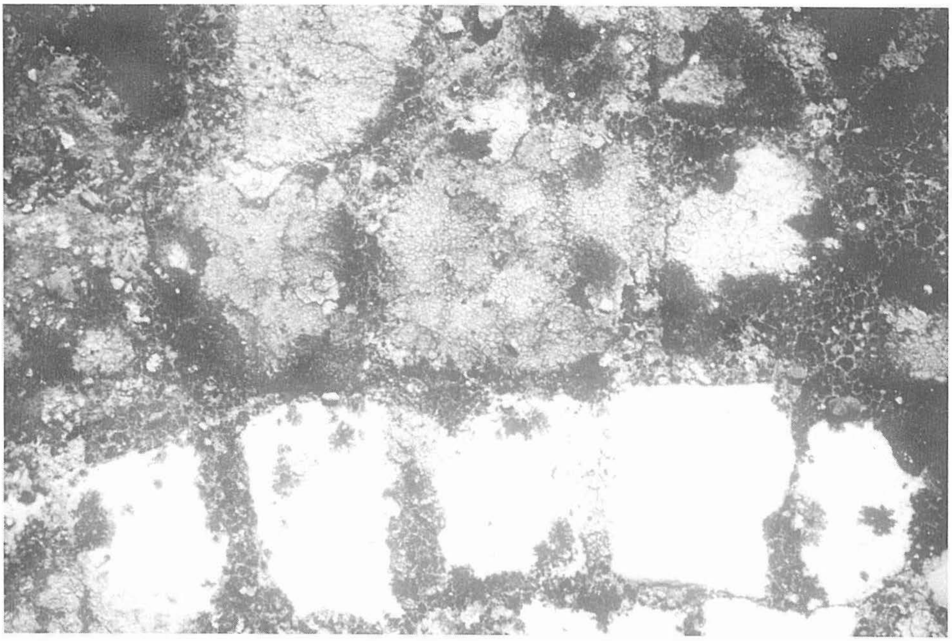


Fig. 7 - Same as Figure 6.

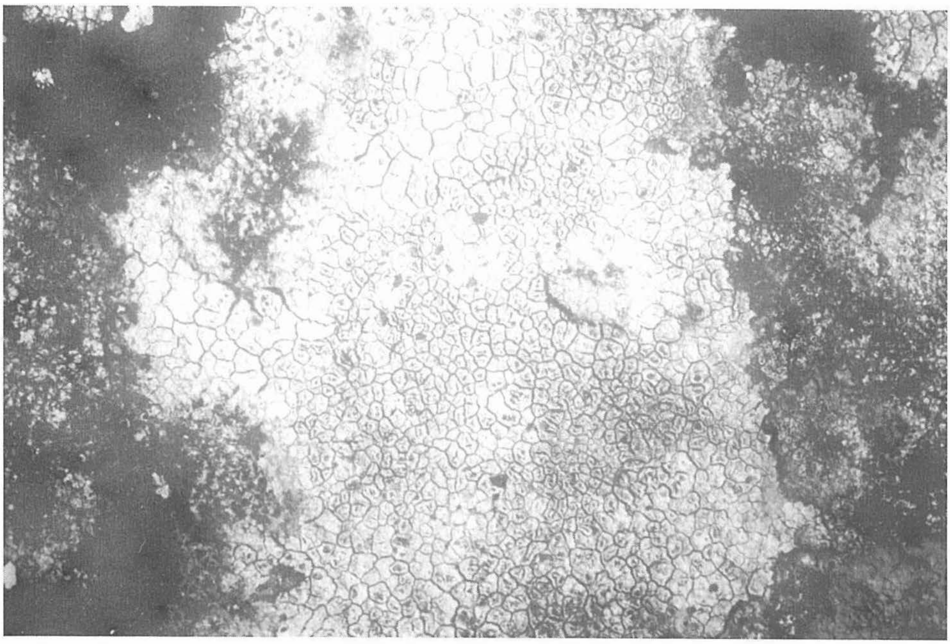


Fig. 8 - Same as Figure 6.

sp. or *Aspicilia* gr. *radiosa*, (Figure 3), with thick crustose thalli and an incipient lower cortex (Clauzade and Roux, 1985) characterize this strategy.

- There is another group of lichens with a less specific ecological behaviour. These lichens spread through both mortar and tesserae due to less exigent substrate requirements. This is the case of *Aspicilia hoffmannii* (Figure 4), with well developed crustose areolate and whitish-gray thallus.

These three types of colonization represent pioneering situation of the mosaic lichen community, defined as heliophylic, xerophytic and nitrophilous. After this, the maturity of the community leads to a fourth stage dominated by less pioneering lichen species, at least in the initial stage of development, such as *Caloplaca* sp. (Figure 5) and *Candelariella vitellina*, giving a colourful character typical of a mature lichen community (Wirth, 1980). In this last stage, the lichens "clothe" the mosaics, in such a way that they mask the figures, destroying their composition and aesthetic value (Figure 6-8).

Cleaning and removal of the lichens are being undertaken in order to preserve the mosaics.

Acknowledgements. This research has been supported by the CICYT through project CE87-0011.

References

Brightman F.H. & B.E. Nicholson, 1977. *Guia de campo de las plantas sin flores.* Omega, Barcelona, 214 pp.

Clauzade G. & C. Roux, 1985. *Likenoj de Okcidenta Europo. Ilustrita Determinlibro.* Bull. Soc. bot. Centre-Ouest, N.S., Nr. Spec. 7.

Iskandar I.K. & J.K. Syers, 1972. *Metal complex formation by lichen compounds.* J. Soil Sci. 23: 255-265.

Rodriguez Hidalgo J.M., 1987. *Mosaicos y Pavimentos. Italica.* Conjunto Arquelogico de Italica, Consejeria de Cultura, Junta de Andalucia, Sevilla.

Seaward M.R.D., 1977. *Lichen Ecology.* Academic Press, London, 550 pp.

Syers J.K., Birnie A.C. & B.D. Mitchell, 1967. *The calcium oxalate content of some lichens growing on limestone.* Lichenologist 3: 409-414.

Wirth V., 1980. *Flecthenflora.* Ulmer, Stuttgart, 522 pp.

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LICHEN COLONIZATION ON STONEWORKS: EXAMPLES FROM PIEDMONT AND AOSTA VALLEY

R. PIERVITTORI and S. SAMPÒ

Keywords: lichen, monuments, Piedmont, Aosta Valley.

Abstract. Data on lichen presence on some monuments from Piedmont and Aosta Valley are reported. Sampling techniques, chosen on the basis of lithological characteristics of the substrata are described, and the ecological significance of the identified species is discussed. Preliminary data indicate that the majority of the species are neutro-basiphytic and rather nitrophytic, xerophytic and photophytic. Finally, most species appear to belong to the *Caloplacion decipientis* alliance.

Introduction

The systematic-ecological study of the organisms responsbile for the degradation of stoneworks is an important preliminary step for an appropriate restoration.

In the case of lichens, this kind of analysis may contribute to a better understanding of the effects of their presence. Lichens could represent a successful defence against atmospheric and/or polluting agents, especially on little consolidated materials, or, on the contrary, they could be a serious threat to the stability of the substrata because of the physical - chemical alterations they could cause.

Furthermore, when lichen species are identified and their physiological characteristics, i.e. their growth rates, are known, this information may be used to date undocumented restorations.

Data and Methods

A systematic and ecological investigation was started on the lichens of some stone artifacts in Piedmont and Aosta Valley. The monuments were: the facade of the Vezzolano Abbey (XXI century, 415 m, Asti) (Piervittori, Sampò, 1987-88), the columns in front of Nostra Signora delle Nevi (XVI century) and the House of the Memorial Stones (XVII century) in Bousson (1419 m, Torino), the Buon Consiglio Church in Rocchetta Palaces (XIX century, 430 m, Asti), The Cly Castle (XII century, 786 m, Aosta).

SUBSTRATA	SPECIES	ECOLOGY (Wirth, 1980) life form	pH	nitro-phytism	xero-phytism	photo-phytism	PHYTOSOCIOLOGY
prasinite 5	*Rhizocarpon geographicum* (L.) DC.	H crust	3.4-5.6	+	/	/	*Rhizocarpetea geographici*
brick 1	*Lecania erysibe* (Ach.) Mudd	H crust	3.7-7	++	+++	+++	*Caloplacion decipientis*
sandstone 1,2; plaster 4; brick 1; cement mortar 2	*Lecanora albescens* (Hoffm.) Florke	H crust	5.7-7	+++	+++	-	*Caloplacion decipientis*
sandstone 1; brick 1	*Lecanora dispersa* (Pers.) Sommerf.	H crust	5.7-7	++	++	-	*Caloplacion decipientis*
sandstone 1; plaster 4; brick 1; prasinite 5; granite 5	*Lecanora muralis* (Schreber) Rabenh.	H crust	5.7-7	+++	++	+	*Aspicilion calcareae*
sandstone 1; brick 1	*Candelariella aurella* (Hoffm). Zahlbr.	H crust	7.1-8	++	+++	++	*Caloplacion decipientis*
sandstone 1; brick 1	*Candelariella medians* (Nyl.) A.L. Sm.	H crust	7	++	++	++	*Caloplacion decipientis*
prasinite 5	*Candelariella vitellina* (Ehrht.) Müll. Arg.	H. crust	4.9-7	+	+++	++	*Rhizocarpetea geographici*
plaster 4	*Caloplaca heppiana* (Müll. Arg.) Zahlbr.	H crust	7.1-8	++	++	++	*Caloplacion decipientis*
plaster 4	*Caloplaca teicholyta* (Ach.) Steiner	H crust	5.7-5	++	+++	++	*Caloplacion decipientis*
sandstone 3; plaster 4; prasinite 5	*Xanthoria elegans* (Link.) Th. Fr.	H fol	4.9-7	++	+++	++	*Caloplacion decipientis*
sandstone 2	*Phaeophyscia orbicularis* (Neck.) Moberg	H fol	4.9-8	+++	++	++	*Caloplacion decipientis*
sandstone 1	*Physconia grisea* (Lam.) Poelt	H fol	5.7-7	+++	++	++	*Xanthorion parietinae*
prasinite 5	*Acarospora sinopica* (Wahlenb.) Korb.	H crust	3.4-4.8	-	+	++	*Acarosporion sinopicae*
sandstone 1,2; cavernous limestone 5; concrete 5	*Collema auriculatum* Hoffm.	H fol	7-8	-	-	+	*Aspicilion calcareae*
sandstone 1,2; plaster 4	*Verrucaria macrostoma* Dufour & DC. s.l.	H crust	7	++	-	-	*Caloplacion decipientis*
limestone 5	*Verrucaria muralis* Ach.	H crust	5.7-7.5	+	+	++	*Aspicilion calcareae*
plaster 4	*Dirina stenhammari* (Fr. ex Stenh.)	H crust	7.1-8	+	+	-	*Caloplacion decipientis*

1. facade of the Vezzolano Abbey; 2. columns in front of Nostra Signora delle Nevi Church; 3. the House of the Memorial Stones; 4. Buon Consiglio Church; 5, Cly Castle.
-, +, ++, +++ = not, little, rather, very.

Given the artistic interest of these monuments sampling methods tried to avoid any form of damage.

Bistouries were used to collect the material and often pre-moistening was required in order to facilitate the removal of lichens from very compact substrata. Crustaceous species were removed using adhesive tape to preserve their whole morphology.

Results

Preliminary data are shown in Tab. 1 (ecological and phytosciological characters are from Ellenberg, 1967; Seaward, 1977; Wirth, 1980).

Generally, sandstones and mortars are the building materials with the densest lichen cover whereas bricks support lichens only when used for flat lying surfaces.

The most common species are *Lecanora muralis* and *Xanthoria elegans* which do not seem particularly affected neither by the type of substrata nor by climatic factors.

The *Candelariellae,* generally have the tendency to colonize edges and contact zones between different surfaces.

The apparently anomalous presence of *Collema auriculatum*, a notoriously hygrophytic species, in a xeric locality such as Bousson can be accounted for by water leaking from nearby buildings.

Most of the species are crustose.

Neutro-basiphytic, xerophytic, photophytic, nitrophytic species prevail. The majority of nitrophytic species are ornitocoprophytic such as *Candelariella aurella, Lecanora albescens, Xanthoria elegans.* Most of the species can be attributed to the *Caloplacion decipientis* Klem. 50, a vegetation common on artificial substrata.

References

Ellenberg H., Dombois M., 1967. *A key to Raunkiaer plant life forms with revised subdivision.* Berichte Geobot. Inst. Rubel., Zürich, 37: 56-73.

Piervittori R., Sampò S., 1987-88. *Colonizzazione lichenica su manufatti litici: la facciata dell'Abbazia di Vezzolano. Asti (Piemonte).* Allionia, 28: 93-102.

Seaward M.R.D., 1977. *Lichen Ecology.* Academic Press.

Wirth V., 1980. *Flechtenflora.* Ulmer, Stuttgart.

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THE LICHEN VEGETATION ON THE CATHEDRAL OF ORVIETO (CENTRAL ITALY)*

P.L. NIMIS & M. MONTE

Keywords: Lichens, Monuments, Orvieto's Cathedral, Vegetation.

Abstract: the lichen vegetation of the Cathedral of Orvieto (Central Italy) has been studied on the basis of 29 phytosociological releves carried out on different parts of the church, and on different substrates. The species by releves matrix has been submitted to classification and ordination to detect different community-types and to study possible ecological gradients. The ecology of the community-types has been studied by means of the ecological indices derived from Wirth (1980). The main causes of lichen growth in different parts of the church, the main aesthetic damages, and the possible measures for eliminating and preventing lichen growth are discussed.

Riassunto breve: LA VEGETAZIONE LICHENICA DEL DUOMO DI ORVIETO. La vegetazione lichenica del duomo di Orvieto è stata studiata sulla base di 29 rilievi fitosociologici effettuati in diverse parti della chiesa, e su diversi substrati. La matrice delle specie e dei rilievi è stata sottoposta a classificazione ed ordinamento al fine di individuare diversi tipi di vegetazione e di evidenziare possibili gradienti ecologici. L'ecologia dei diversi tipi di vegetazione è stata studiata utilizzando le diagnosi ecologiche proposte da Wirth (1980) per le singole specie. Vengono discussi le principali cause che determinano la crescita dei licheni nelle diversi parti del Duomo, i principali danni estetici da essi creati, e possibili misure di intervento per eliminare e prevenire la crescita dei licheni nella parti maggiormente colpite.

Introduction

Stone monuments are frequently colonized by lichens. This implies several conservation and restoration problems, for whose solution the following points are of importance:
a) Acquisition of information on the type of damages caused by lichens. The damage may be purely aesthetic (chromatic alterations), or chemico-physical (alterations of the properties of the rock surface);
b) choice of elimination techniques. These may be based on the application of biocides, on mechanical means, or on both. The choice of the best techniques depends on knowledge related to points a), c), d), and e);
c) information on the consequences of elimination. These are particularly evident in the case of endolithic lichens (Nimis et al. 1987), where the elimination of the

* This study has been financed by M.P.I. funds 40 and 60%, to P.L. Nimis.

lichens implies the abrasion of a thin rock layer;
d) information on the causes of lichen growth. Many interventions risk to be ephemerous if the main causes of lichen growth are not eliminated. This is particularly evident in the case of nitrophytic lichens, which have a relatively rapid growth; their elimination should be accompanied by a reduction of the main eutrophication sources (e.g. bird excrements);
e) information on the reproductive strategy of lichens. The purely mechanical elimination of some sorediate species might be not sufficient, since it does not allow the elimination of all small vegetative propagules (soredia). In such cases the intervention should be accompanied by the application of appropriate biocides.

This study concerns the lichen vegetation of Orvieto's Cathedral, in Central Italy (Umbria Region, Province of Perugia). Its main aim is to acquire informations on: a) types of lichen vegetation present on the monument, b) their location on the monument, c) main ecological factors affecting lichen growth on different parts of the monument, d) main types of damages caused by lichens. Such informations are indispensable to start any intervention aimed at eliminating lichen growth.

Data and Methods

This study is based on 29 phytosociological releves carried out in different parts of Orvieto's Cathedral. The Cathedral is one of the most famous examples of Italian Gothic; it is located at the top of Orvieto's hill, at ca. 325 m; the church is oriented in an east-west direction, the main façade facing west. The walls are built with alternating bands of white limestone and black basaltic rocks; marble has been used chiefly to decorate the main façade.

Each releve consists in a list of species present on a surface of 20 x 20 cm, A cover value has been assigned to each species, according to the following scale:

+ = less than 1%
1 = 1-20%
2 = 21-40%
3 = 41-60%
4 = 61-80%
5 = 81-100%

The location of the releves on the church is as follows:
Releves 1 to 4: Statues under the tympanum of the main façade (marble).
Releves 5 to 12: Upper part of the lower tympanum (travertine).
Releves 13 to 17: lower part of the lower tympanum.
Releves 18, 26 to 29: basement at the northern side of the Church (limestone), at 50 cm aboveground.
Releves 19, 22: northern side of the church, at 1.5-2.5 m, on limestone.
Releves 20, 21, 23 to 25: northern side of the church, at 1.5-2.5 m, on basaltic rock.

The southern side of the church hosts a very poor and fragmentary lichen ve-

Tab. 1 - Phytosociological table of lichen vegetation. The releves and the species are ordered as in the respective dendrograms.

Sp.Nr.	Releve Group Nr.	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	3	3	3	3	3	4	4	4	4	5	5	5	5	5
	Releve Nr.	15	13	17	14	11	7	16	8	6	5	10	9	12	22	19	27	26	18	28	29	4	2	3	1	25	24	21	20	23
12	*Physcia orbicularis*	1	2	+	3	+		+				3	1																	
11	*Caloplaca teicholyta*	+	+	+	+			+					+																	
36	*Lecanora dispersa*	+	+		+															+										
8	*Xanthoria calcicola*	1	1		+						1			1																
20	*Physcia adscendens*	+	+																											
29	*Physcia dubia*			+	+																									
18	*Xanthoria parietina*	+	1																											
17	*Lecanora muralis s.str.*	+	2			+																								
19	*Physconia grisea*		+																											
7	*Caloplaca flavescens*	3	1	3	+	1	1	4	+	2	1	+	+																	
5	*Caloplaca granulosa*		+		+	1	+			1	+	+																		
6	*Caloplaca saxicola*	+	1	1	1	+	1		+		1	+	3	1	+	+										+			+	
4	*Lecanora albescens*	1	1	2	2	2	4	1	3	+	1	1	+	3	1	1	1	+	+	1	+	+	+	1						
2	*Caloplaca biatorina v.gyalolechiodes*	+	1	+	+	+			1	+	1	+	+	1								3	2	3	2					
35	*Rinodina bischoffii*																+	+												
34	*Caloplaca citrina*																+	+			+									
32	*Catillaria lenticularis*																+	+	+											
22	*Verrucaria marmorea*																1	2	3	3	1									
23	*Verrucaria parmigera*																	+	+	1										
33	*Lecania turicensis*																	+			+									
16	*Verrucaria nigrescens*			+	+	+						+			+		+	1	+	1	+									
3	*Candelariella aurella*		+	+	+		+										+	+	+			+	1		+					
25	*Lecanora muralis v.versicolor*															+														
21	*Aspicilia contorta*														+	1				1										
14	*Caloplaca lithophila*											+	+																	
1	*Caloplaca erythrocarpa*	+						+	+			+																		
13	*Aspicilia calcarea*	+										1	+	+	+				1	1	1									
9	*Caloplaca aurantia*									+	1	+	+	+	3	2			2	+	1									
15	*Aspicilia hoffmannii*	+											+					+	+											
10	*Candelariella medians*	+							+				+		+					+										
28	*Haematomma ochroleucum v. ochrol.*																									1	1	+	+	+
37	*Haematomma ochrol. v. porphyrium*																									3	3		+	1
26	*Tephromela atra*																									+	+	1	2	+
31	*Lecidella stigmatea*																									+	1	1	+	
30	*Candelariella vitellina*																									+	+	1	+	
27	*Lecanora sulphurea*																									+	+	2	2	1
24	*Diploicia canescens*																									2	+	1	+	
38	*Dirina massiliensis f. sorediata*																									+	+	+	+	+

getation, so that no releve has been carried out there. Other parts of the church were not accessible during the survey period.

The matrix of the species and of the releves (Tab. 1) has been submitted to multivariate analysis in order to tipify the vegetation and to quantify the relations between its compositional variation and the variation of some main ecological factors. Ecological information has been derived, in an indirect way, from the ecological diagnoses proposed by Wirth (1980), regarding pH requirements, tolerance to eutrophication, moisture requirements, and light requirements of the species. The diagnoses have been transformed into Ecological Indices, on an or-

Tab. 2 (a-d): occupancies of different ecological indices' classes (expressed as percentages), subdivided by releve groups. a) pH index, b) eutrophication index, c) hygrophytism index, d) photophytism index.

Releve Groups nr.	1	2	3	4	5
A - pH 3.4-4.0	.....	.....	.....	.....	13.3
B - pH 4.1-4.8	.....	.....	.....	.....	30.0
C - pH 4.9-5.6	4.8	.....	.....	.....	46.6
D - pH 5.7-6.9	15.9	4.4	.....	.....	40.1
E - pH 7.0	44.4	33.3	46.1	42.1	20.0
F - pH 7.1-8.5	55.5	51.1	46.1	100.0	26.6
G - pH > 8.5	74.6	100.0	100.0	85.7	20.0
a)					
A - anitrophytic	.....	8.8	28.2	.....	43.3
B - moderately nitrophytic	53.9	64.7	58.9	84.7	93.3
C - rather nitrophytic	98.4	71.1	66.6	100.0	40.0
D - very nitrophytic	76.1	53.3	58.9	84.7	20.0
E - extremely nitrophytic	22.2	26.6	23.5	42.8	.....
b)					
A - rather hygrophytic	9.5	8.8	17.9	.....	33.3
B - mesophytic	53.9	37.3	38.5	.....	100.0
C - rather xerophytic	100.0	91.1	89.7	100.0	70.0
D - very xerophytic	58.7	64.4	23.1	100.0	20.0
c)					
A - moderately photophytic	47.6	97.7	41.0	42.8	60.0
B - photophytic	92.1	84.4	74.3	100.0	100.0
C - very photophytic	95.2	61.5	48.7	100.0	86.6
d)					

dinal scale, as proposed by Nimis & Dallai (1985) and Nimis et al. (1987). Tab. 2 reports the incidence of the species in each index-class for each releve group obtained by numerical classification of the data in Tab. 1, expressed as percentages of the total occupancies. Data elaboration may be summarized as follows:
1) Classification of releves and of species, to obtain releve groups with similar composition (vegetation types), and groups of species with similar ecological behaviour. The algorithm used for classification is Complete Linkage Clustering (Anderberg, 1973), using the Correlation Coefficient as resemblance measure, on binary data (program package by Wildi & Orloci, 1980).
2) Canonical Concentration Analysis (AOC) on the contingency table of the groups of species and of releves, to quantify the correlation among groups. The program used is AOCRO (Feoli & Orloci, 1979).
3) Reciprocal Ordination of species and releves, carried out on the data of Tab. 1, trasformed by deviation from expectation, using Cross Product as a resemblan-

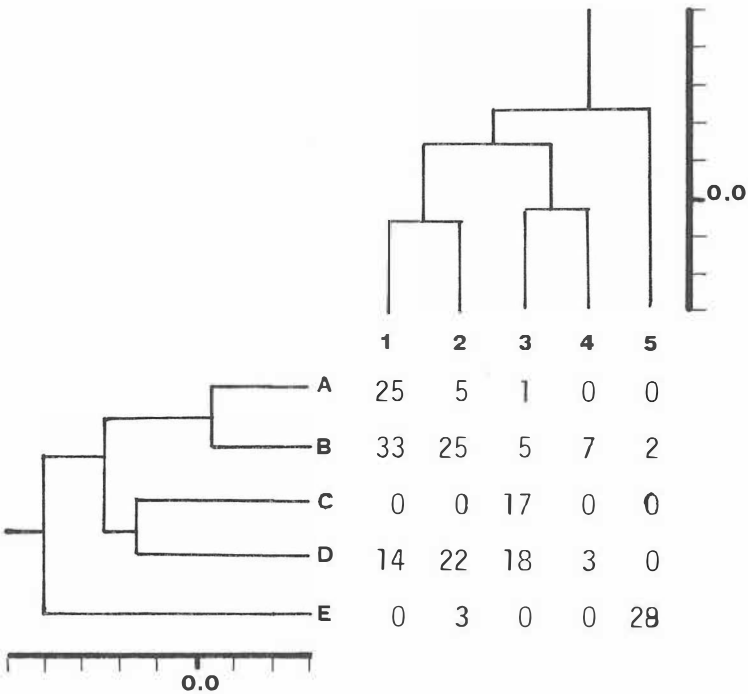
ce measure, to detect possible ecological gradients, and to study the response of single species to these gradients. (program package by Wildi & Orloci, 1980).
4) Canonical Concentration Analysis (AOC) on the data of Tab. 2 (a-d), to order the releve groups along four main ecological gradients (pH, tolerance to eutrophication, humidity, light). The program used is AOCRO (Feoli & Orloci, 1979).

The nomenclature of the species follows Nimis et Poelt (1987).

Results

The dendrograms of the species and of the releves, and the contingency table of species and releve groups are shown in Fig. 1. The classification of the species produces 5 main species groups (A-E) at a fusion level of 0.01 of the Correlation Coefficient. The classification of the releves forms 5 main releve groups (1-5) at a fusion level of 0.1 of the Correlation Coefficient. The correlations between species and releve groups are shown in Fig. 2, that reports their position in the space defined by the first two canonical variates of AOC. These results may be summarized as follows:

Species group A: among the most frequent species are *Physcia orbicularis, Ca-*



	1	2	3	4	5
A	25	5	1	0	0
B	33	25	5	7	2
C	0	0	17	0	0
D	14	22	18	3	0
E	0	3	0	0	28

Fig. 1 - Dendrogram of the releve groups (numbers) and of the species groups (letters), with the contingency table of releve and species groups, obtained by numerical classification of the data in Tab. 1.

loplaca teicholyta, Lecanora dispersa, Xanthoria calcicola, Lecanora muralis s. str. This group is correlated with releve group 1, including the releves carried out on the lower tympanum of the main façade.

Species group B: among the most frequent species are: *Caloplaca flavescens, Caloplaca granulosa, Caloplaca saxicola, Lecanora albescens, Caloplaca biatorina* var. *gyalolechioides.* This group is correlated with releve groups 1, 2 and 4 (lower tympanum, calcareous belts above 1.5 m aboveground at the northern side of the church, and statues under the upper tympanum).

Species group C: among the most frequent species are: *Verrucaria marmorea, Catillaria lenticularis, Caloplaca citrina.* This group is correlated with releve group 3 (calcareous basement of the northern side of the church).

Species group D: among the most frequent species are: *Caloplaca aurantia, Aspicilia calcarea, Verrucaria nigrescens, Candelariella aurella.* This group has the highest correlation with releve groups 2 and 3.

Species group E: among the most frequent species are: *Dirina massiliensis* fo. *sorediata, Tephromela atra, Candelariella vitellina, Lecanora sulphurea, Haematomma ochroleucum.* This group has a strong correlation with releve group nr.

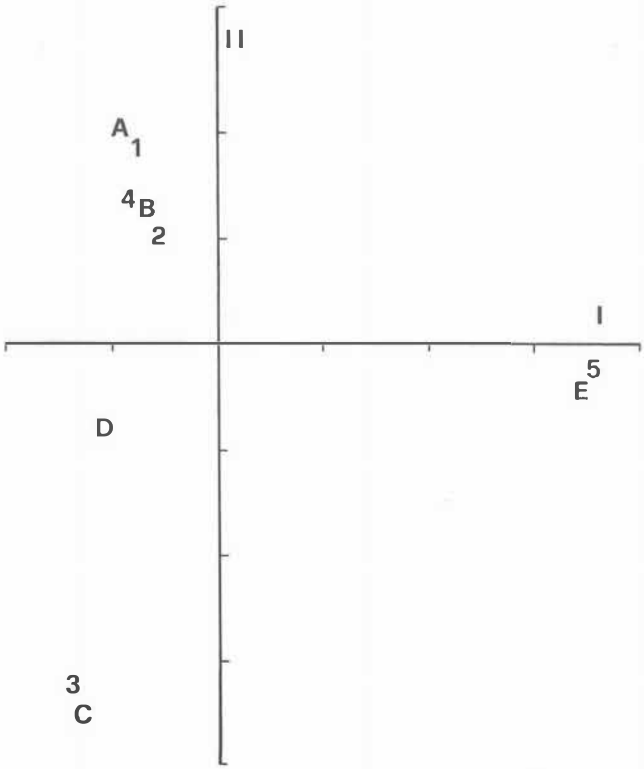


Fig. 2 - Arrangement of releve group (numbers) and species group (lettes) points according to the two first canonical variates of AOC, performed on the contingency table of Fig. 1.

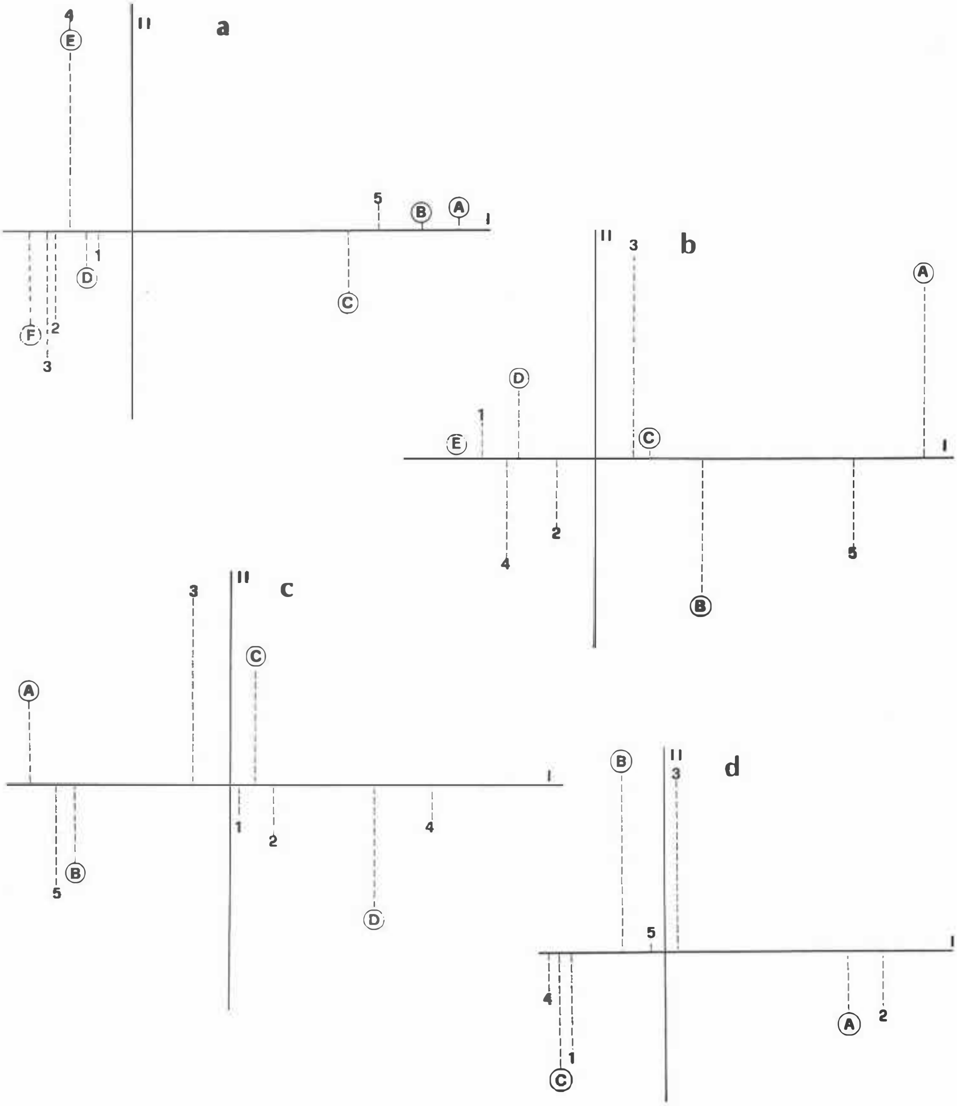


Fig. 3 - Arrangement of releve group points (numbers) and
a) pH-classes points (letters) according to the two first canonical variates of AOC, performed on the data of Tab. 2a.
b) nitropyhtism-classes points (letters) according to the two first canonical variates of AOC, performed on the data of Tab. 2b.
c) moisture-classes points (letters) according to the two first canonical variates of AOC, performed on the data of Tab. 2a.
d) photophytism-classes points (letters) according to the two first canonical variates of AOC, performed on the data of Tab. 2a.

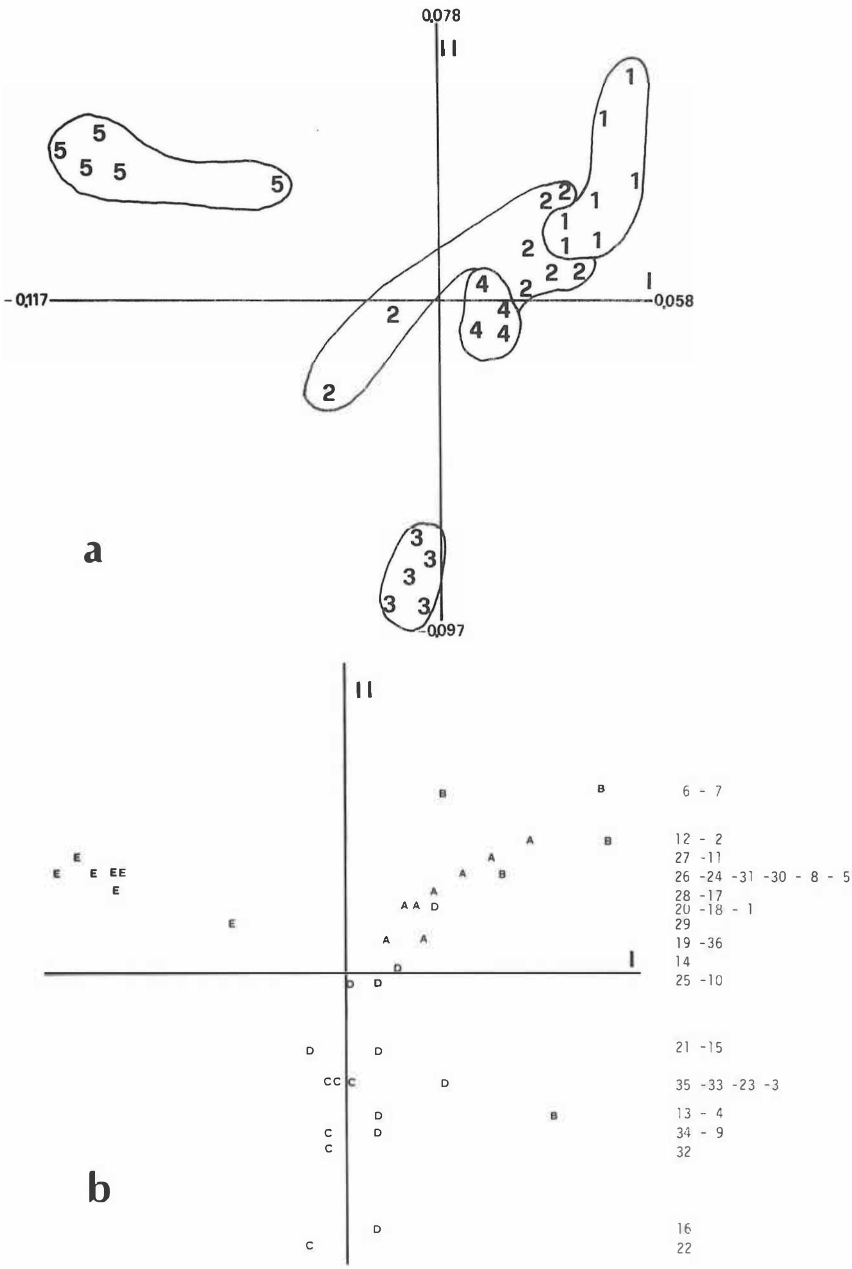


Fig. 4 - Reciprocal ordination of: a) releves b) species, performed on the data of Tab. 1. In Fig. 4a the releve groups are numbered as in Tab. 1. In Fig. 4b the species groups, and the single species are numbered as in Tab. 1.

5 (basaltic substrate, northern side of the church).

The ecological characterization of the 5 releve groups is shown in Fig. 3 (a-d), reporting the arrangement of the releve groups and of the classes of ecological indices in the space defined by the first two canonical variates of AOC. The results may be summarized as follows:

pH requirements (Fig. 3a): first canonical variate: 92.6% of the total chi square, second canonical variate: 4.83%. Sequence of the releve groups along the first canonical variate (from basiphytic to acidophytic): groups nr. 4, 3, 2, 1, 5. Releve group nr. 5 is well distinguished for the prevalence of subacidophytic species (basaltic substrate).

Eutrophication (Fig. 3b): first canonical variate: 90.9% of the total chi square, second variate: 5.06%. The sequence of the releve groups along the first canonical variate (from strongly nitrophytic to anitrophytic) is: 1, 4, 2, 3, 5. Releve groups 1, 4, and 2 are characterized by the prevalence of nitrophytic species (eutrophication of the substrates by bird excrements).

Moisture requirements (Fig. 3c): first canonical variate: 92.8% of the total chi square, second variate: 5.73%. Sequence of the releve groups along the first variate (from hygrophytic to xerophytic): groups nr. 5, 3, 1, 2, 4. The less xerophytic groups are nr. 5 and nr. 3, i.e. those including releves carried out on the northern façade of the church.

Light requirements (Fig. 3d): first canonical variate: 93% of the total chi square, second variate: 6.99%. Sequence of the releve groups along the first variate (from little to very photophytic): groups nr. 2, 3, 5, 1, 4.

According to these results, the 5 releve groups may be ecologically characterized as follows:

Group 1: neutrophytic, very nitrophytic, rather xerophytic, very photophytic.
Group 2: basiphytic, nitrophytic, rather xerophytic, little photophytic.
Group 3: basiphytic, moderately nitrophytic, rather xerophytic, moderately photophytic.
Group 4: very basiphytic, very nitrophytic, very xerophytic, very photophytic.
Group 5: subacidophytic, anitrophytic, rather hygrophytic, moderately photophytic.

The reciprocal ordination of releves and species is shown in Fig. 4 (a: releves, b: species). The groups of species and of releves obtained by classification are still recognizable in the ordination. The first principal component separates releve group nr. 5 (basaltic substrate) from all the others (calcareous substrates). The second principal component separates releve group nr. 3 from group 1, 2 and 4. This separation does not seem to be justified on the basis of the ecological characterization of this releve group. The reason for its distinction along the second variate is probably the different lithological character of the limestone of the northern basement, which has a finer crystalline texture with respect to the other calcareous substrates present on the church. Some species which characterize releve group nr. 3 (e.g. *Verrucaria marmorea, V. parmigera)* prefer to grow on compact limestone. The ordination of the species (Fig. 4b) should be interpreted in

conjunction with the ordination of the releves: the arrangement of the species points in the space defined by the two principal components reflects their correlation with the compositional gradient revealed by the ordination of the releves.

Discussion

Southern side

The southern façade has a very poor lichen cover, both on the basaltic and on the calcareous belts. There are a few, isolated thalli of *Lecanora dispersa* and *Candelariella aurella* on limestone, scarce individuals of *Candelariella vitellina* on basalt. The reason of the scarce lichen growth is probably the strong insolation, and consequently the strong evaporation; this renders the environment too dry for the development of a rich lichen vegetation. The few lichen species occurring on this side of the church have very small, fragmentary thalli, so that the aesthetic damage is practically non-existent. No intervention is needed on the southern side of the church.

Main Façade (facing west)

The densest lichen cover is concentrated on the lower tympanum. Bright coloured species (yellow-orange) are dominant, which implies a strong chromatic alteration of the stone. Most of the species are nitrophylous: the main cause for their growth is the frequent presence of birds. Lichen growth is concentrated on the tympanum since this is made up of very porous calcareous rock; the porosity of the substrate slows down evaporation and helps the concentration of nitrogen compounds. The young lichen thalli start their development within small niches of the rock, from which they spread later over the entire surface. Parts of the tympanum have been substituted, and replaced with hard limestone, where lichens are very scarce. Given the rapid growth of most nitrophytic species, the simple elimination of lichens will have probably ephemerous results, if not accompanied by other measures, such as the treatment of the rock surfaces with synthetic protective substances, the protection against rain water or the elimination of birds. Besides the upper tympanum, nitrophytic lichens are present also in some parts of the façade where there is periodical percolation of water. The chromatic alteration is rather evident, although these surfaces are generally small; also in this case the removal of lichens should be accompanied by a removal of the causes of their growth, i.e. of water percolation.

Other parts of the main façade with a rather dense lichen cover are the statues located below the upper tympanum and part of the marbles. The statues are colonized by a few species, chiefly *Caloplaca biatorina* var. *gyalolechioides* and *Candelariella aurella*. The total cover is low, and the chromatic alteration is not particularly evident, notwithstanding the bright colour of the thalli of *Caloplaca*. On the statues, *Caloplaca* is most abundant on rain-protected surfaces; being a relatively slow-growing xerophytic lichen, its elimination should be less epheme-

rous than in the case of the nitrophytic lichens.

Northern side

Calcareous basement: it is dominated by endolithic lichens, chiefly *Verrucaria parmigera* and *V. marmorea*. The chromatic alteration is not particularly serious (pale pink and whitish gray). Any measure to remove the lichens runs the danger of secondary effects, which might be more serious than the damage deriving by lichens themselves. Even the application of biocides, killing the lichen within the rock, may produce, on the long run, a strong alteration of the rock surface, which becomes very porous and sensible to corrosion, besides assuming a pure white colour contrasting with that of the other parts of the building.

Calcareous bands: the greatest aesthetic damage is produced by nitrophytic lichens, chiefly *Caloplaca aurantia* (orange colour). The cause of the growth of these lichens is the presence of water percolating from the windows of the church. To hinder lichen growth one should eliminate this percolation, which should be possible with rather simple measures. The calcareous bands not interested by water percolation are colonized by almost pure populations of *Dirina massiliensis* fo. *sorediata*, which, owing to its white thallus, does not produce any chromatic alteration of the surfaces; its presence on the northern side of the church is probably related to lower evaporation rates, and hence to higher humidity with respect to the southern side.

Basaltic bands: the lichens growing on basalt are responsable of the greatest aesthetic damage on the whole church. The dominant species. *Haematomma ochroleucum* var. *porphyrium* and *Tephromela atra*, have a whitish thallus covering relatively large surfaces. The result is that on most of the northern side of the church the characteristic alternation of white and black bands is almost completely lost. The mechanical removal of lichens is difficult, owing to the uneven surface of the basaltic rock. Furthermore, *Haematomma ochroleucum* produces abundant soredia, which should be eliminated to prevent further lichen growth after the intervention.

Conclusions

The lichen vegetation on Orvieto's Cathedral is concentrated on the lower tympanum of the main façade, and on the northern side of the church. The southern side is almost devoid of lichens, probably because of its high aridity (strong insolation). The principal cause of lichen growth is the eutrophication of the subsrates by bird excrements, which are spread by percolating water. On the main facade lichen cover is densest on the tympanum, because this structure is made of porous calcareous stone. On the northern side the less arid conditions allow lichens to grow also on more compact stones (compact limestone and basalt). Lichens should be removed from the tympanum (which presently is orange-coloured by the presence of several nitrophytic lichens), and from the basaltic bands of the northern façade, which have lost their black colour because of the dominance of

light-coloured lichens. Lichen removal should be accompanied by measures preventing their further growth, chiefly by a better regulation of the water percolating from the upper parts of the church.

Riassunto. La vegetazione lichenica del Duomo di Orvieto è stata studiata sulla base di 29 rilievi fitosociologici, effettuati in varie parti della chiesa, su diversi substrati. La matrice delle specie e dei rilievi è stata sottoposta a programmi di analisi multivariata, al fine di individuare tipi diversi di vegetazione e possibili gradienti ecologici. L'ecologia della vegetazione è stata studiata per via indiretta utilizzando gli indici ecologici di Wirth (1980). Le parti del Duomo di Orvieto maggiormente colonizzate da licheni sono il timpano della facciata principale e tutto il lato nord della chiesa. Sul timpano ed in alcuni punti della facciata nord la causa principale dell'instaurarsi dei licheni è data dall'eutrofizzazione del substrato da parte di uccelli che frequentemente si posano sulle parti alte della chiesa. L'eutrofizzazione si diffonde ad opera di acque percolanti, che scolano, in alcuni punti, direttamente sui muri della chiesa. Sul lato nord, le condizioni di minore xericità fanno si che i licheni coprano vaste superfici. Di particolare gravità è l'attacco, da parte di specie a tallo di colore chiaro, delle bande basaltiche, per cui si perde l'effetto estetico dato dalla caratteristica alternanza di bande scure e chiare. Gli interventi principali dovrebbero interessare il timpano della facciata principale e le bande di basalto. Si sottolinea che per una maggior efficacia degli interventi di asporto, questi dovrebbero venir accompagnati dall'eliminazione delle principali cause della crescita dei licheni; si ritiene che una migliore regolazione degli scoli d'acqua piovana sulla chiesa potrebbe determinare una sensibile riduzione dei licheni nitrofili a tallo vivacemente colorato.

References

Anderberg M.R., 1973. *Cluster Analysis for Applications*. Academic Press. New York. 359 p.

Feoli E. & L. Orloci, 1979. *Analysis of Concentration and detection of underlying factors in structured tables*. Vegetatio, 40: 49-54.

Nimis P.L. & D. Dallai, 1985. *Lichens of hypogaeic cavities in the Apennines of Reggio Emilia (N-Italy)*. Le Grotte d'Italia, 4, 12: 373-382.

Nimis P.L., M. Monte & M. Tretiach, 1987. *Flora e Vegetazione Lichenica di Aree Archeologiche del Lazio*. Studia Geobot., 7: 3-161.

Nimis P.L. & J. Poelt, 1987. *The lichens and Lichenicolous fungi of Sardinia (Italy). An annotated list*. Studia Geobot., 7, Suppl. 1, 269 pp.

Wildi O. & L. Orloci, 1980. *Management and multivariate analysis of vegetation data. 2nd ed.* Swiss Fed. Inst. For. Res., Birmensdorf. rep. nr. 215. 139 p.

Wirth V., 1980. *Flechtenflora*. Ulmer. Stuttgart. 552 pp.

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THE DISTRIBUTION OF LICHENS ON SOME STONEWORKS IN THE SURROUNDINGS OF ROME

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Keywords: Lichens, Stoneworks, Monuments, Ecology.

Abstract: 34 floristic releves concerning epilithic lichens have been carried out in 6 archaeological sites in the surroundings of Rome, on different types of substrate. 52 lichen species have been recorded. The matrix of the releves and of the species has been submitted to programs of multivariate analysis (classification and ordination); the results allow to distinguish 5 main community-types and to order the species according to their degrees of acidophytism and nitrophytism.

Introduction

The role of lichens in the deterioration of stoneworks is still open to discussion. Deterioration by lichens can occur in the following ways: a) Increase of the thallus in time, b) variation of the thallus volume following drying and wetting, c) the capacity of the thallus to absorb water, which becomes particularly important under freezing conditions, d) the secretion of acids and other substances that can alter the rock surface. The CO_2 produced by the respiration of the lichens, in the presence of water, may attack the rock surfaces, producing pittings or small channels which make easier the penetration of the hyphae into the rock.

As for conservation, lichens are sometimes removed from the stoneworks to avoid mechanical, chemical, or purely aesthetic damages. However, these measures are not always based on informations on the ecology of the various species. Ecological information appears to be a very important point, since the removal of lichens should be accompanied by other measures for the prevention of lichen growth. This paper aims at giving a preliminar contribution on the ecology of lichens growing on different substrate-types in some archaelogical areas of Latium.

Data and Methods

34 floristic releves have been carried out in 6 localities, on four substrate types. The localities are:
1) Scavi di Ostia

2) Isola Sacra
3) Tombe Latine
4) Museo Nazionale Romano
5) Villa Madama
6) Caprarola, Palazzo Farnese.

The main substrate types are:
a) carbonatic rocks, including marble and travertino
b) pyroclastic rocks, deriving from the quaternary volcanic areas of Latium; sometimes they contain calcareous inclusions. Among the most frequent rock types are the grey granular tuff (peperino), and the yellow tuff of Via Tiberina, which were widely used in Roman buildings.
c) artificial rocks (cement, brick, etc.);
d) basaltic rocks, mainly used for pavements and walls.

The matrix of the 34 floristic releves and of the 52 lichen species is reported in Tab. 1. The location of the single releves is reported in the Appendix.

The data in Tab. 1 have been submitted to numerical classification in order to obtain groups of releves with similar floristic composition. The clustering algorithm is complete Linkage Clustering (Anderberg, 1973); the resemblance measure is Euclidean Distance. The same matrix has been further submitted to Reciprocal Ordering, with data transformed by Deviation from Expectation and with Cross Product as resemblance measure (see Orloci, 1978), in order to detect possible variation trends, and to analyze the correlations between species and releves. Classification and ordination have been carried out with the program package of Wildi & Orloci (1983). Nomenclature follows Nimis & Poelt (1987).

Results

The dendrogram of the releves is shown in Fig. 1: five main releve groups are formed. As shown in Tab. 2, most of the groups are well characterized by one or more differential species, as follows:
Group 1: *Lecanora muralis, Candelariella vitellina, Lecidea fuscoatra, Porpidia sp., Candelariella coralliza, Acarospora fuscata, Aspicilia cinerea.*
Group 2: *Dirina massiliensis.*
Group 3: this is an heterogeneous group; the first three releves have no differential species, the last four releves are characterized by the high frequency of *Lepraria incana* and *Tephromela atra.*
Group 4: *Lecanora dispersa, Caloplaca citrina.* Frequent species, shared with group 5, are: *Lecanora albescens, Caloplaca aurantia, Verrucaria nigrescens.*
Group 5: *Aspicilia calcarea, Bagliettoa baldensis.*

In the ordination of releves (Fig. 2a), the sequence of the releve groups along the first Principal Component is the following: 5, 4, 2, 3, 1. The first Principal Component clearly reflects a gradient in the pH of the substrate, since all releves on limestone have negative scores, all releves on siliceous rock have positive scores. Fig. 2b shows the arrangement of the indicator species along the First Compo-

nents: they are arranged, from left to right, according to increasing acidophytism.

The second component separates *Lecanora dispersa* and *Caloplaca citrina,* two nitrophytic species correlated with releve group 4, from all other calciphytic species, and represents a gradient of increasing nitrophytism (from the negative to the positive scores). Although less clearly, this gradient also applies to the silicicolous species with positive scores on the first Principal Component. *Xanthoria calcicola, Xanthoria parietina, Candelariella vitellina, Lecanora muralis and Acarospora fuscata,* which are rather nitrophytic species, have positive scores on the Second Principal component, whereas *Tephromela atra,* a species which is less tolerant to eutrophication, has negative scores.

Summarizing, the space defined by the two first Principal Component, can be subdivided into 4 quadrants, as follows:
Quadrant 1 (first PC negative, second PC positive): basic pH, eutrophiated substrates.
Quadrant 2 (both PCs positive): acid pH, eutrophiated substrates.
Quadrant 3: (first PC positive, second PC negative): acid pH, non- eutrophiated.
Quadrant 4: (both PCs negative): basic pH, non-eutrophiated.

The results of these elaborations show that the two main factors responsible for the floristic variation within our data set are, in order, pH and eutrophication of the substrates. The releves of group 3 have low absolute scores on either PC, and are not related to these factors.

Discussion and Conclusion

The most frequent species are: *Aspicilia calcarea, Caloplaca aurantia, Caloplaca citrina, Caloplaca holocarpa, Candelariella vitellina, Lecanora albescens, Lecanora dispersa, Lecanora muralis, Bagliettoa baldensis, Verrucaria nigrescens, Xanthoria parietina, Lecidea fuscoatra.* Most species appear to be linked to a particular type of substrate (siliceous or calcareous), with the exception of a few lichens with broader ecological amplitude such as *Physcia adscendens, Xanthoria calcicola, Xanthoria parietina* and *Diploicia canescens.*

Considering that our releves are limited to floristic lists, often taken on small surfaces, it is not easy to attribute each releve group to a given lichen association. However, by comparing our results to those of Nimis et al. (1987), the following considerations can be made:
Releve group 1: it partially corresponds to releve group M3 of Nimis et al. (1987).
Releve group 2: it corresponds with the *Dirinetum repandae* (group M1 of Nimis et al., 1987), an association linked to low light intensity on subvertical or overhanging surfaces.
Releve group 3: it partiallycorresponds with releve group M2 of Nimis et al. (1987). occurring on subvertical surfaces in rather shady, humid sites.
Releve group 4: it corresponds to releve group C4 of Nimis et al., 1987 *(Caloplacion decipientis),* including nitrophytic communities on limestone.
Releve group 5: it appears as a very fragmentary facies of the *Aspicilietum cal-*

Tab. 1 - Floristic releves.

SUBSTRATE	C	C	C	M	P	C	M	C	M	M	M	M	C	C	B*	P	C	P	M	M	M/P	C	M	C	C	C	C	C	C	C	M	M	M	P	
RELEVE NR.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	**NR. OF OCCURRENCIES**
SPECIES																																			
Acarospora fuscata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	-	x	-	-	x	-	-	-	-	-	-	-	-	-	-	-	-	-	3
Acarospora umbilicata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-	1
Aspicilia calcarea	x	-	x	x	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	x	-	-	-	-	6
Aspicilia cinerea	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	x	-	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3
Buellia punctata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Caloplaca aurantia	x	x	-	-	-	-	x	-	-	-	x	x	x	x	-	-	x	-	-	-	-	-	-	-	x	x	x	-	x	x	-	-	-	-	13
Caloplaca citrina	-	-	-	x	-	x	x	x	-	x	-	-	x	-	-	-	-	-	-	-	x	x	-	x	-	-	x	-	-	-	-	-	-	-	10
Caloplaca festiva	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	2
Caloplaca holocarpa	-	x	-	-	-	-	-	x	-	-	-	-	-	x	-	-	-	-	-	-	-	-	-	x	-	-	-	-	x	x	-	-	-	-	6
Caloplaca saxicola	-	-	-	-	-	-	x	-	-	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
Candelariella coralliza,	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	-	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
Candelariella medians	-	-	-	-	-	-	-	-	x	-	-	-	-	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
Candelariella vitellina	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	x	-	x	-	-	x	-	x	-	-	-	-	-	-	-	-	-	-	-	5
Collema crispum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	-	-	1
Collema tenax	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	-	-	-	1
Diploicia canescens	-	-	-	-	-	-	-	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-	-	-	x	-	-	-	-	-	-	-	-	x	3
Diplotomma epipolium	-	-	-	-	-	-	-	-	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Dirina massiliensis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	-	1
Dirina repanda repanda	-	-	-	-	-	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	-	-	-	x	-	-	-	-	-	-	3
Haematomma ochroleucum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	1
Huilia sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	-	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
Lecania erysibe	-	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Lecanora albescens	x	x	-	x	x	x	x	x	-	-	-	x	x	x	-	-	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	11
Lecanora atra	-	-	-	-	x	-	-	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	3
Lecanora campestris	-	-	-	-	x	-	-	-	-	-	-	-	-	-	-	x	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3
Lecanora crenulata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	-	-	-	-	-	-	-	-	-	-	1
Lecanora dispersa	-	x	-	x	-	x	x	-	-	x	-	-	x	-	-	-	-	-	-	x	-	x	x	-	x	-	x	-	-	-	-	-	-	-	11
Lecanora muralis	-	-	-	-	-	-	-	-	-	-	x	-	-	-	x	x	-	x	-	-	x	-	x	-	-	-	-	-	-	-	-	-	-	-	6
Lecanora pruinosa	-	-	-	-	-	-	-	-	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Lecanora rupicola	-	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Lecanora soralifera	-	-	-	-	-	-	-	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Lecidea fuscoatra	-	-	-	-	-	-	-	-	-	-	x	-	-	-	-	-	-	x	-	-	x	-	x	-	-	-	-	-	-	-	-	-	-	x	5
Lecidella stigmatea	-	-	-	-	-	-	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	-	-	-	-	-	-	-	-	-	2
Leprarla lncana	-	-	-	-	x	-	-	-	-	-	x	-	-	-	-	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3
Leproplaca chrysodeta	-	-	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Leproplaca xantolyta	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	-	-	-	-	-	-	-	-	-	-	1
Ochrolechla parella	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	2
Opegrapha mougeotii	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Parmelia verruculifera	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	2
Phaeophyscla orbicularis	-	-	-	-	-	-	-	-	x	-	-	-	-	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-	x	-	-	-	-	-	3
Physcla adscendens	-	-	-	-	x	-	x	-	-	-	-	-	-	-	-	-	x	-	-	-	-	-	-	-	-	x	-	-	-	-	-	-	-	-	4
Physconla grisea	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	-	-	-	-	-	-	-	-	1
Protoblastenia rupestris	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	-	-	-	-	-	-	-	-	-	1
Rhlzocarpon geographycum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	1
Rhizocarpom obscuratum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	1
Rinodina gennarii	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-	-	1
Roccella phycopsis	-	-	-	-	-	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Sarcogyne regularis	-	-	-	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Scoliciosporum umbrinum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	-	-	-	-	x	x	-	-	-	-	-	-	-	3
Toninia aromatica	-	-	-	-	-	x	-	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
Verrucaria baldensis	-	-	-	-	-	-	-	x	-	-	-	-	-	x	-	-	x	-	-	-	-	-	-	-	-	-	-	-	x	x	-	-	-	-	5
Verrucaria fuscella	-	-	-	-	x	-	-	x	-	-	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	-	-	-	-	4
Verrucaria glaucina	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	-	-	-	x	-	-	-	-	-	2
Verrucaria muralis	-	-	-	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Verrucaria nigrescens	-	-	-	-	-	-	x	x	-	x	-	x	-	x	x	-	x	-	-	x	-	-	-	x	x	x	-	-	x	-	-	-	-	-	12
Verrucaria viridula	-	-	-	-	-	-	-	x	-	x	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3
Xanthoria calcicola	-	-	-	-	-	-	x	-	-	-	-	-	x	-	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3
Xantboria parietina	-	x	-	-	-	-	-	-	-	-	-	-	x	-	-	x	-	x	-	-	-	-	-	-	-	x	-	-	-	-	-	-	-	-	5
																																			179
RELEVE NR.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	

Abbreviations: C: carbonatic rocks, B: pyroclastic rocks, M: artificial materials, B: basalt.

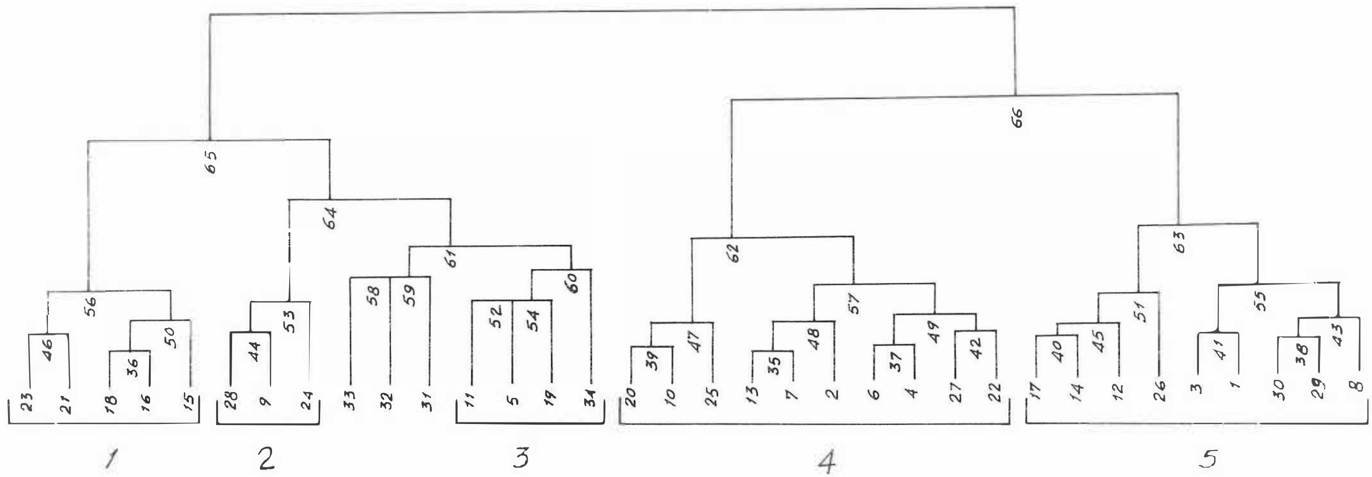


Fig. 1 - Dendrogram of the releves.

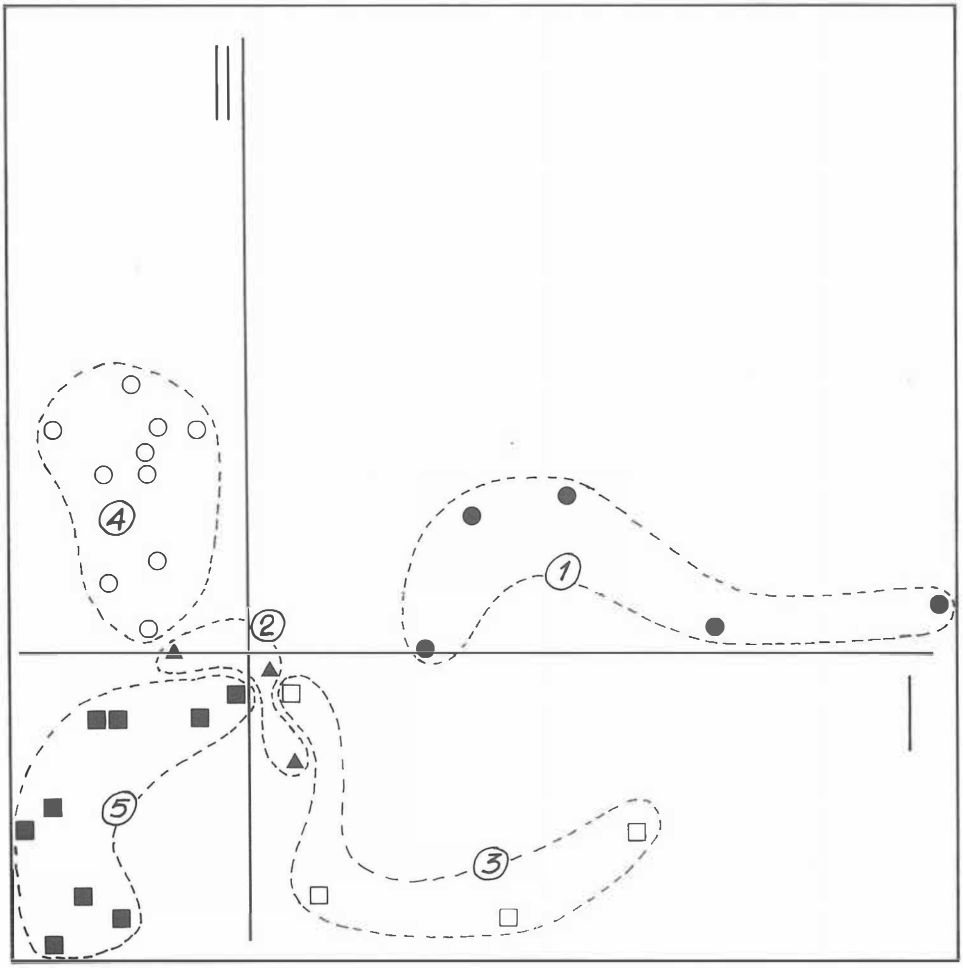


Fig. 2a - Ordination of the releves.

careae (releve group C3 of Nimis et al., 1987), a less nitrophytic association than those of the *Caloplacion decipientis.*

As far as lichen action on the substrates is concerned, the following observations have been made:

Large terra-cotta vases (Phitos) at the Museo Nazionale Romano are colonized by the thalli of *Lecanora muralis,* which can attain a diameter of 4-7 cm, with an estimate age of about 8-15 years. The section of one of the thalli revealed a damage to the substrate, with the detachment of a few mm thick substrate fragments; the lichen appeared to be particularly aggressive, in the absence of other species probably due to air pollution. A comparison can be made with other terra-cotta vases (Ollae) in a more natural environment (Ostia Antica). In this case the

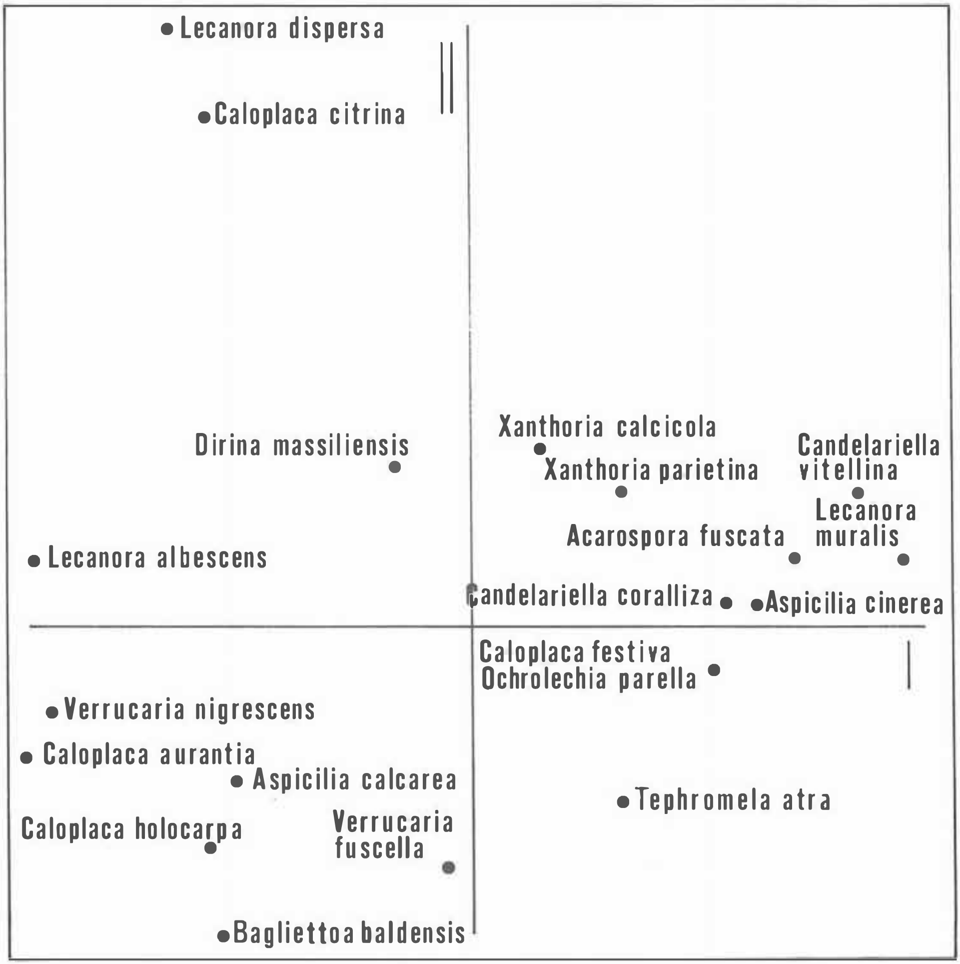


Fig. 2b - Ordination of the species.

colonizing lichen is *Tephromela atra,* that also caused the detachment of small substrate fragments mixed with parts of the thallus. Another example of heavy damage is given by the mural paintings of Palazzo Farnese at Caprarola, close to Viterbo; the paintings were colonied by *Dirina massiliensis,* causing small shallow cavities at the surface of the paintings (Seaward et al, 1989).

There is still much work to be done on the problem of lichens and stoneworks. Two points are of particular interest:

1) The detailed study of different species' action on different substrates.

2) The testing of different techniques which are currently used to remove lichens from the substrata.

Furthermore, there is a general agreement on the fact that lichens should be

removed only in presence of serious mechanical or aesthetic damage. If removal is necessary, it is important to take measures for preventing further growth, and these must be based on the knowledge of the ecology of the single species. This study gives a first floristic-ecological information on which to base further research.

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Bibliografia

Anderberg M.R., 1973. *Cluster analysis for application.* Academic Press, New York. 359 pp.

Caneva G., Rocardi A., Marenzi A. & I. Napoleone, 1985. *Proposal for a data base on biodeterioration of stone artworks.* Vth International Congress on deterioration and conservation of stone. Losanna, Vol. 2, pp. 587-596.

Lallemant R. & S. Deruelle, 1978. *Presence des lichens sur les monuments en pierre: nuisance ou protection?* UNESCO-Rilem, Internat. Symp. on Deterioration and Protection of Stone Monuments, Paris.

Nimis P.L., Monte M. & M. Tretiach. 1987. *Flora e vegetazione lichenica di aree archeologiche del Lazio.* Studia Geobotanica 7: 3-161.

Nimis P.L. & J. Poelt, 1987. *The lichens and lichenicolous fungi of Sardinia (Italy).* An annotated list. Studia Geobotanica, 7, suppl. 1. 269 pp.

Orloci L., 1978. *Multivariate analysis in vegetation research.* 2nd ed Junk. the Hague. 451 pp.

Seaward M.R.D., Giacobini C., Giuliani M.R. & A. Roccardi, 1989. *The role of lichens in the biodeterioration of ancient monuments with particular reference to central Italy.* International Biodeterioration 25, pp. 49-55.

Appendix
Localities of sampling and releve numbers

OSTIA SCAVI
1) Travertino basement, 2) Temple of Attis, marble statue, 3) Campo della Magna Mater, column basement (travertino) 4) Porta Laurentina, brick, 5) Porta laurentina, Opus Reticulatum, tuff, 6) Porta Laurentina, door, travertino, 7) Columns of the Forum, cement, 8) Marble blocks in the Forum, 9) Capitolium, brick, 10) Wall painting of Via Diana, 11) Campo delle Olle, terracotta.

ISOLA SACRA
12) Tombe a Cappuccina, terracotta, 13) Marble grave.

TOMBE LATINE
14) Basement, travertino, 15) Basalt boulder, 16) Peperino boulder, 17) Travertino boulder, 18) Tuff blocks, 19) Tomba dei Valeri, brick, 20) Tomba dei Pancrazi, brick.

MUSEO NAZIONALE ROMANO
21) Funerary Monument of Fontei, tuff, peperino, cement, 22) as before, marble fragment, 23) Terracotta Phitos.

VILLA MADAMA
24) Venus statue, marble, 25) Sarcophagus, marble, 26) Columns, granite, 27) Column, limestone, 28) Part of the door, travertine, 29) Giants' statue, basement, travertine, 30) Balaustra della Balconata, travertine, 31) Vase, calcareous conglomerate (cement), 32) Garden pavement, calcareous conglomerate (cement)-

CAPRAROLA
33) Palazzo Farnese, wall paintings, 34) Palazzo Farnese, statues and other stoneworks of the garden, tuff, peperino.

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PROTECTIVE AGENTS AS A POSSIBLE SUBSTRATE FOR BIOGENIC CYCLES

P. ALESSI and D. VISINTIN

Keywords: Conservation, Monuments, Protective agents.

Abstract - Protective agents are increasingly used for the preservation of stone monuments. Once applied to the rock, they constitute a veritable new substrate. Very little is known on the biological cycles which could develop on treated surfaces. This paper presents a synthesis on the main properties of protective agents, with particular regard to those of biological relevance; the results were obtained on the basis of multivariate analysis of solubility data. The aim of the paper is to provide biologists with an information basis for studies of biogenic cycles on treated surfaces.

Introduction

Lichens are amongst the most common organisms which may be harmful to stoneworks. According to Savoye & Lallemant (1980), and contrary to a common belief, lichens are not the first colonizers of bare rock: lichen ecesis occurs only after a micropedogenesis started by bacteria on a substrate prepared by chemical wheathering. Organic matter, mostly zoogenous, is the primary substrate of the nitrogen cycle, started first by ammonificant, then by nitrificant bacteria; lichens appear only 5 years from the beginning of the cycle. The sulphur cycle starts slowly with the chemical neutralization of sulphuric acid by the rock bases; since sulphur is taken up by lichens as sulphate ion, also chemical wheathering creates favourable conditions for lichen growth (Lazzarini & Tabasso, 1986; Carrol, 1970).

In recent times, chemical protective agents are increasingly used for the preservation of stone monuments. They include a wide variety of synthetic resins, with different chemical and physical properties. Once applied to the rock, they constitute a veritable new substrate. There is no detailed information on the biological cycles developing on treated rock surfaces, although the use of protective agents should not hinder the development of bacterial microsuccessions which could culminate in lichen ecesis. The study of biological cycles on these artificial substrates seems to be an interesting field, which could be of relevance for protection measures. Aim of this paper is to present to biologists a synthesis on the main properties of the principal families of protective agents, particularly of those with most direct biological relevance, such as solubility in water and polluting

Tab. 1 - Solubility of 33 organic compounds in 9 protective substances, expressed as normalized ponderal activity coefficients at infinite dilution.

		PERFLUORO POLYETHER FOMBLIN Y MET	PERFLUORU POLYETHER ISOTHYLAMMIDE/FOMBLIN A.	ACRYLIC RESIN PARALOID B 72	EPOXYLIC RESIN ARALDITE	SILOXANE OLIG.	POLYURETHANE	FLUOROCOMPOUND 16H6F	PERFLUOROPOLYETHER GALDEN D20	PERFLUOROPOLYETHER KRYTOX AX
1	WATER	13	11	7	10	10	9	13	13	13
2	n-PENTANE	7	6	5	8	4	6	4	7	8
3	n-HEXANE	7	7	5	8	4	6	4	7	9
4	n-HEPTANE	8	7	5	8	3	6	3	7	9
5	1 PENTENE	7	6	4	8	4	5	4	7	8
6	1 HEXENE	7	7	5	8	3	5	4	7	9
7	1 HEPTENE	8	7	5	8	3	6	3	7	9
8	METHANOL	12	10	6	8	7	6	10	11	13
9	ETHANOL	12	9	4	7	6	6	9	11	13
10	PROPANOL	11	8	4	7	5	5	8	11	13
11	METHYLACETATE	8	6	3	6	4	4	5	7	9
12	ETHYLACETATE	8	6	3	6	3	4	4	7	9
13	PROPYLACETATE	8	6	3	6	3	4	4	7	10
14	ACETONE	9	6	4	5	4	5	6	8	9
15	METHYL ETHYL KETONE	9	6	3	6	3	4	5	8	10
16	METHYL ISOBUTYL KETONE	7	5	2	6	1	3	2	7	8
17	ETHYLIC ETHER	7	6	3	7	3	5	4	7	8
18	TETRAHYDROFURANE	7	6	3	6	2	3	3	7	9
19	BENZENE	8	7	3	6	3	3	4	7	9
20	TOLUENE	8	7	3	6	3	3	4	7	9
21	ETHYLBENZENE	9	7	3	6	3	4	3	8	10
22	CHLOROFORM	6	5	1	5	1	1	3	6	7
23	TETRACHLOROMETHANE	6	5	1	5	1	1	2	6	7
24	METHYLENCHLORIDE	7	6	1	5	2	2	3	7	8
25	CHLOROPROPANE	7	6	3	6	3	4	4	7	8
26	CHLOROBUTANE	7	6	3	6	3	4	3	7	8
27	ACETO NITRILE	11	9	5	7	6	6	8	11	12
28	PROPIO NITRILE	11	8	4	7	6	5	7	10	11
29	BUTYRO NITRILE	10	8	4	6	5	5	6	10	10
30	NITROMETHANE	11	9	3	7	6	5	7	10	12
31	CYCLOHEXANE	7	7	3	7	3	5	4	7	8
32	METHYLCYCLOHEXANE	7	7	4	7	3	5	3	7	8
33	ETHYLCYCLOHEXANE	8	7	4	7	3	5	3	8	9

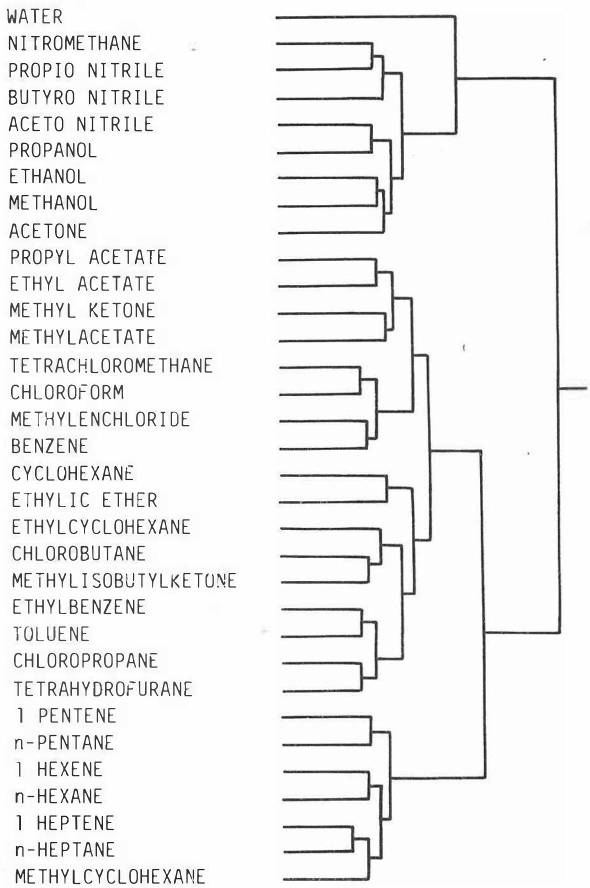


Fig. 1 - Dendrogram of the solvents, based on the data in Tab. 1.

gases, and their behaviour towards the main organic solvents.

Main properties of chemical protective agents

Stoneworks may be protected by two different approaches: a) modifying the environment, b) modifying the interface between the rock suface and the environment (Pasetti, 1984). The latter involves the use of protective substances. These may be subdivided into two main types: a) Plasters or washings for reducing the penetration of water; wheathering acts on the new substrates, protecting the underlying rock (Guidotti, 1985); their use often creates aesthetical problems. b) Chemical protective agents, which are water repelling, transparent synthetic substances. The main characteristics of a protective agent are: A) Chemical and physical inertia towards the atmosphere (incl. pollutants), to avoid chromatical

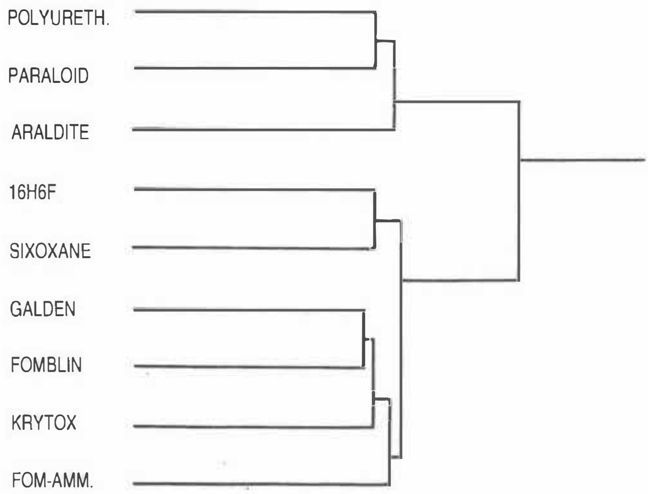


Fig. 2 - Dendrogram of the protective agents, based on the data in Tab. 1.

or physical modifications. B) Chemical and physical inertia toward the rock. C) Transparence and absence of colour. D) Hydrorepellence and insolubility in water and in the common organic solvents, to ensure the stability of the rock surface. E) Low volatility, to ensure duration in time. F) Permeability to gases (air and water vapour), to avoid the formation of a water film below the protective agent, seat of solubilization phenomena with the subsequent fall of crusts from the treated area; the rock pores should not be filled by the agent, which should just cover their internal surface to increase the surface tension on the pore walls, and hence to increase water-repellence. G) Reversibility of the treatment.

The main protective agents

The protective materials may be subdivided in: a) Metallic soaps b) Microcristalline waxes, c) Organic polymers. The latter, which are the most widely used, include:

1) Epoxydic systems. Main properties (Marinelli, 1975): a) they cross-link at standard temperature without forming by-products, becoming insoluble; b) they require the use of medium-high polarity solvents, because of their high viscosity, or because they are solid at standard temperature. b) they resist well to water, alcohols, salt solutions, acids and to the most common organic solvents. c) they have a very good adherence to lithic materials. Main disadvantages: a) the treatment is non-reversible, b) with small amounts of solvent the pores are obstructed, with too little solvent the protection is insufficient, c) aromatic groups in the molecule make them chromatically instable to UV-rays d) they are hydrophobous also before cross-linking, which creates problems in cases of high humidity. Applica-

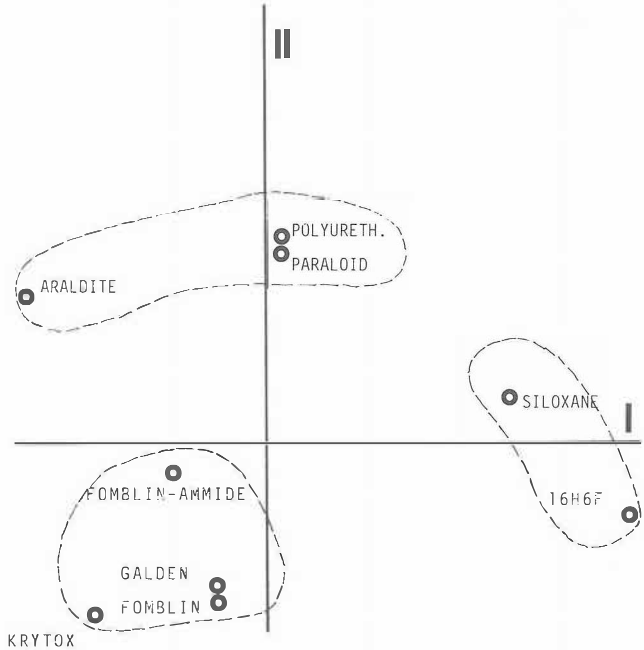


Fig. 3 - Ordination of protectives (centered on the similarity matrix of protectives), based on the data in Tab. 1.

tions: Loggetta del Sansovino in Venice (parts in Verona red marble).

2) Acrylic resins: thermoplastic polymers from several acrylic compounds; widely used, also together with siliconic products. Main advantages: a) Long-lasting effect, b) chemical inertia, resistance to UV-rays, c) good adherence to rock,due to a polar part in the molecule, d) reversible treatment. Main disadvantages: a) the film is often not continuous inside the pores, b) not very high resistance to water. Applications: Gate of the Arsenale and base of Colleoni's statue in Venice, scultures of ''anime oranti'' in Rome, low-reliefs of the Orvieto Cathedral.

3) Poliuretanic systems: presently little used, but potentially interesting. They have optimal chemical inertia, stability under sunlight, rapid dessiccation, optimal water-repellence, high adhesion to the rock; the disadvantages are the same of the cross-linked polymers.

4) Organic Silica compounds: they are the most widely used in the last decade, with a very broad choice of substances; among the most used are alkyl-silanes, alkossi-silanes, polyxilossanes, olygomerous xylossanes. Their common properties are (Biscontin et al., 1986): optimal adhesion to the rock, good chemical inertia, high water-repellence, good permeability to water vapour, good resistance towards breaking off by thermic expansion. Main disadvantages: low resistance to UV-rays, non-complete reversibility, short duration, alteration in humid environ-

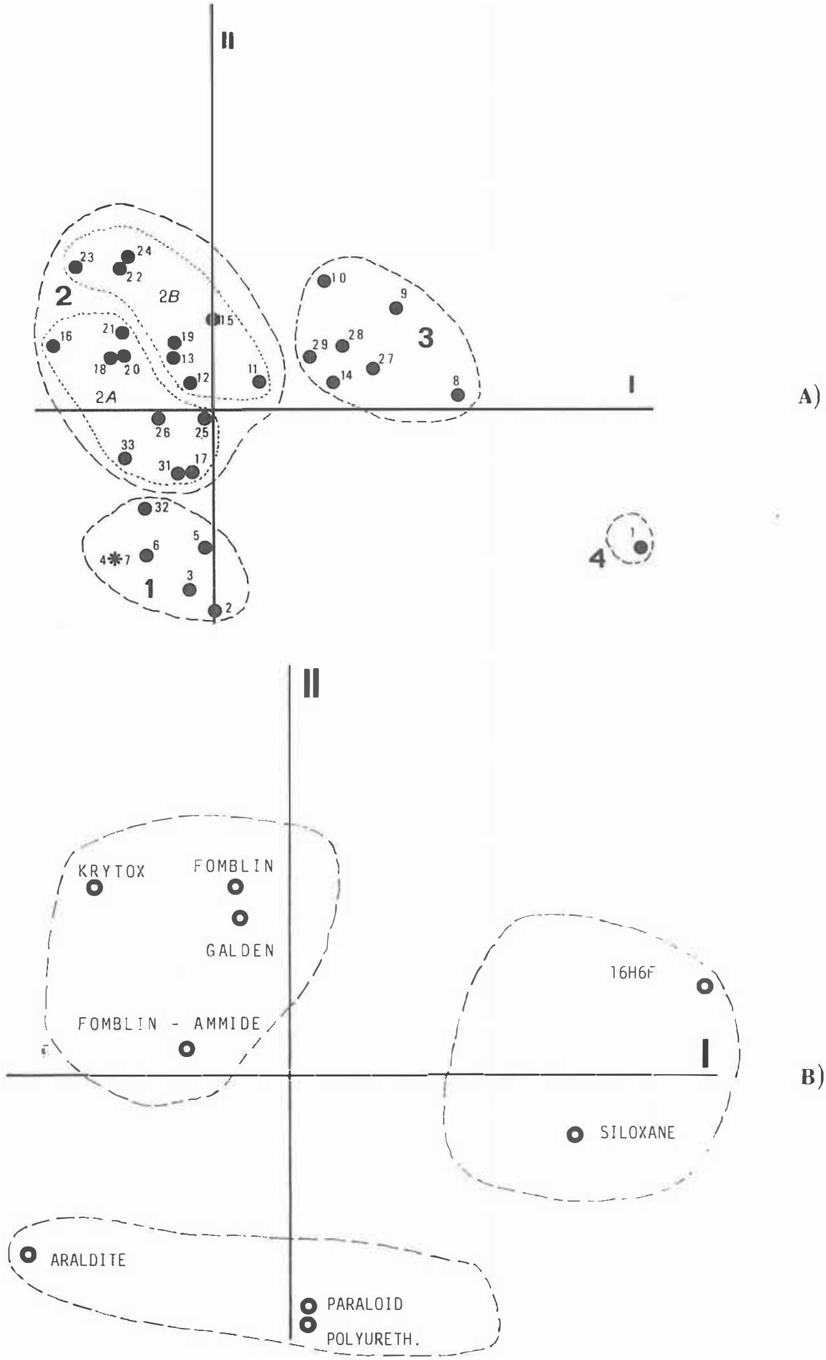


Fig. 4 - Reciprocal ordering of solvents (a) and protectives (b) (centered on the similarity matrix of solvents), based on the data of Tab. 1.

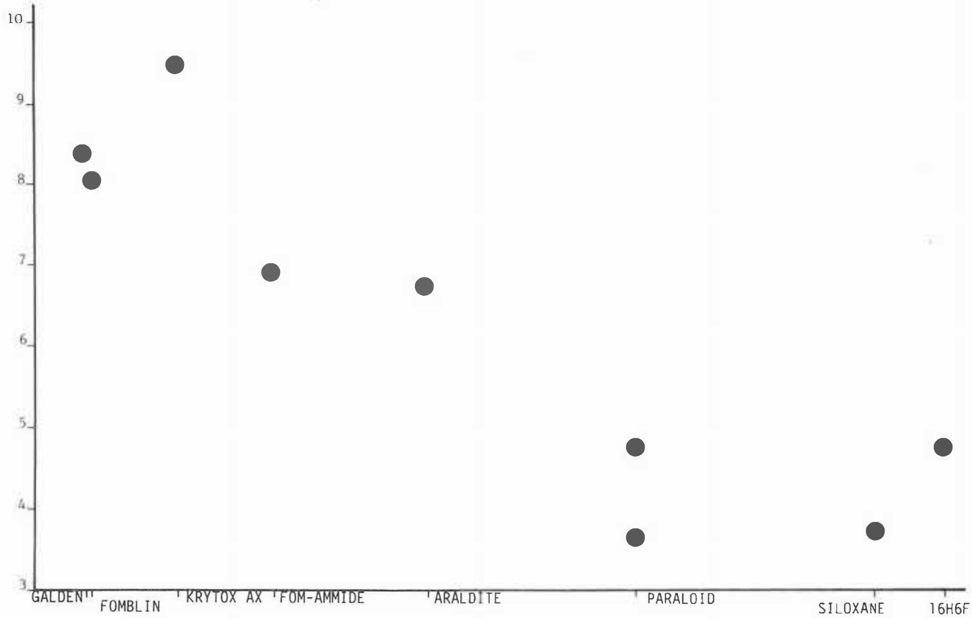


Fig. 5 - Relation between the scores of the protectives on the first canonical variate (x-axis, see Fig. 3) and their inertia (y-axis) expressed by averaging the values of Henry's constant of each solvent in each protective.

ments, loss of the protective agent by evaporation. The high variety of substances is the cause of wrong choices which proved to be detrimental to the stonework. Applications: Town Hall of Vienna, Justizpalast and Town Hall of Munich, Certosa of Milan.

5) Fluoro-compounds (Banks, 1974); they are chemically and thermically stable. There are different polymers, with different molecular weights, so to allow the choice to optimal viscosity. The fact that they are soluble in trichlorotrifluorethane allows their use as impregnators of weakly porous materials (marbles). They are almost non-volatile at standard temperature, non toxic, insoluble in organic solvents, non inflammable, strongly water repellent. Laboratory and field experiments proved that Fomblin Y Met is permeable to water vapour, and that the treatment is easily reversable (Pasetti, 1984). The main disadvantages are: the use of potentially harmful chlorofluoro-compounds as solvents, the low surface tension, which helps the migration of the protective agents inside the rock, particularly when this is very porous. To overcome this problem some perfluoropolyesters have been synthetized, having some functional groups such esters, ammide, acids: the presence of polar groups reduces the mobility of the molecule, crating bonds with the rock surface (Piacenti et al., 1985). Applications: Cathedral of Florence, S. Zeno Closter in Vienna, Antinori and Pitti Palaces in Florence.

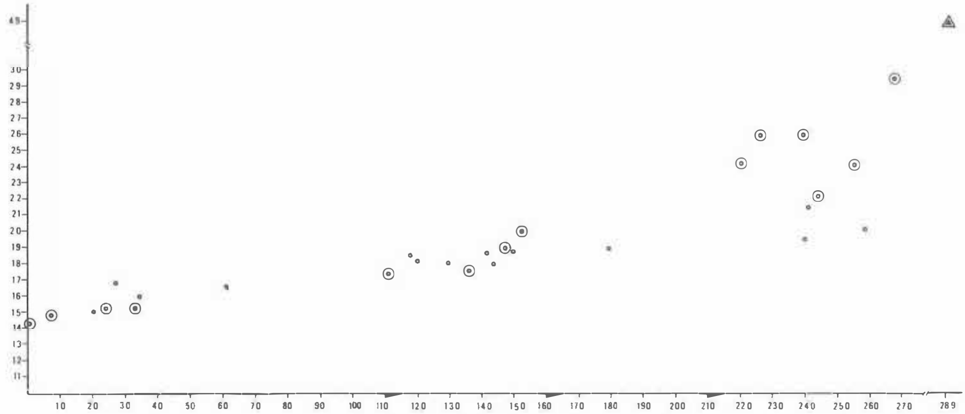


Fig. 6 - Relation between the scores of the solvents on the first canonical variate (x-axis, see fig. 4a) and their polarity, expressed by Hildenbrandt's constant (y-axis).

Data and methods

The migration of a solute in a chromatographic column depends on the distribution ratio of the solute between the stationary phase (polymer or resin), and the mobile one (inert gas). The volume of mobile phase is necessary for moving the solute out of the column, is known as specific retention volume. From the magnitude of the chromatographic retention it is possible to derive some thermodynamic values which are bound to the solubility of the solute in a given solvent. In the case of gaseous solutes the relation is known as Henry's constant (Reid et al., 1977). In the case of liquids one uses the ponderal activity coefficient at infinite dilution (Laub et Pecsok, 1978). In this study we use the values of Henry's constant and of the ponderal activity coefficient for 10 gases, 33 solvents and water in the 11 stationary phases utilized during laboratory work.

This paper analyzes the interactions between both pollutants and protective agents, and organic solvents and protective agents. In both cases we selected the protective in such a way as to have representatives of two main groups: one including a series of partially fluorurated substances, the other a series of organic polymers, already used as protectives in several cases. The considered protective agents and the solutes are listed in Tab. 1 and Tab. 2.

The matrices of the solvents and the protectives (solubility expressed by gamma), and of the gases and the protectives (solubility expressed by Henry's constant), have been submitted to multivariate analysis, as follows:

1) Numerical Classification (Anderberg, 1973), to obtain groups of correlated variables. We have used the package of programs of Wildi & Orloci (1983), utilizing Correlation Coefficient as a resemblance measure, and Complete Linkage (see

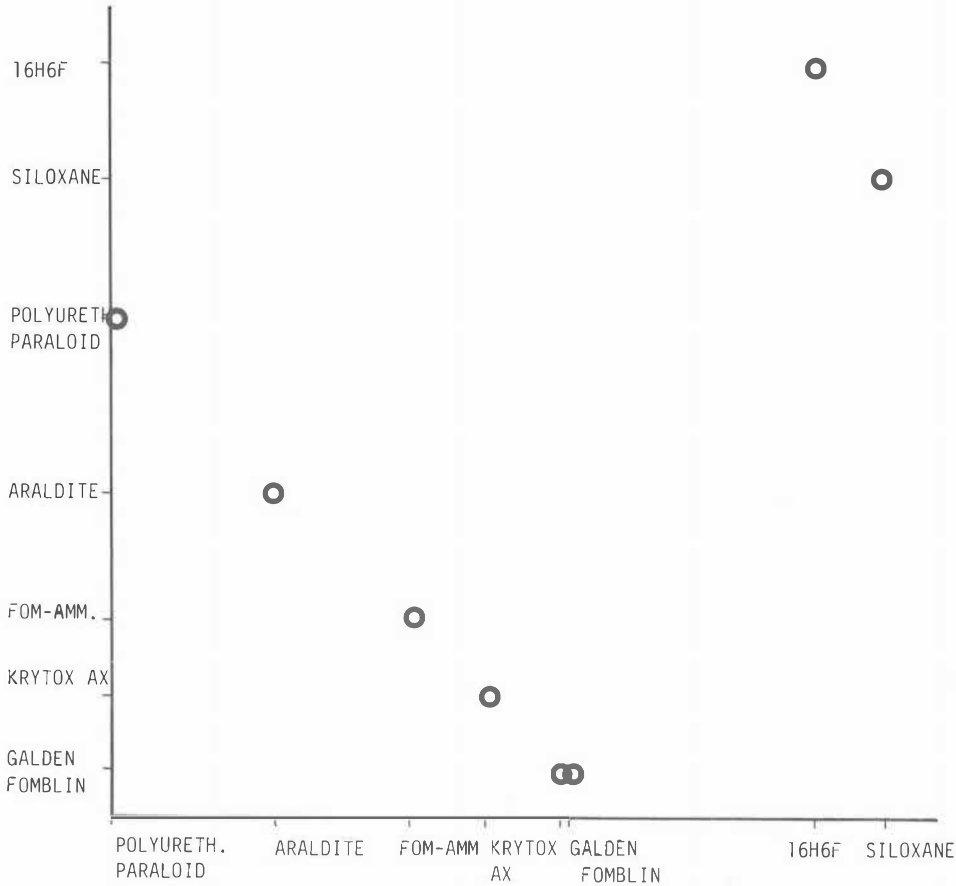


Fig. 7 - Comparison between the two ordinations of protectives: the two axes report the scores of the protectives on the first canonical variates as in Fig. 3 and 4b.

Orloci, 1978) as classification algorithm.

2) Reciprocal Ordering, to evaluate the possible existence of variation trends in the data structure. The ordination has been obtained by transforming the original data by deviation from expectation, and on a resemblance matrix based on Cross Product. Also in this case the package of Wildi & Orloci (1983) was used.

Results

Tab. 1 reports the normalized values of the ponderal activity coefficients relative to the solubility of 33 organic compounds in 9 protective substances. The data of Tab. 1 have been analyzed by classification and reciprocal ordination in

Tab. 2 - Solubility of 10 gases in 11 protectives, expressed as normalized values of Henry's constant.

	ARALDITE	KRYTOX AZ	KRYTOX AX	POLYURETHANE	SILOXANE OLIG.	PARALOID B72	FOMBLYN AMMIDE	FOMBLYN Y MET	GALDEN D 20	16H6F	12H8F
O_2	5	8	5	2	7	9	9	1	1	0	1
N_2O	9	5	6	9	6	1	5	7	8	4	4
CO_2	9	4	2	5	1	3	5	7	8	4	5
CO	9	7	9	6	1	9	8	4	5	3	4
FREON 13	9	4	5	9	6	2	4	6	4	4	4
SO_2	9	5	6	3	4	9	4	7	6	4	4
PROPYLENE	9	5	6	7	4	8	5	7	6	2	2
ETHANE	8	7	9	8	7	9	4	8	9	4	6
H_2O	5	6	6	3	4	1	7	9	8	7	8
H_2S	0	8	8	0	0	3	4	4	7	4	5

order to: 1) Define group of solvents with similar behaviour towards the protective agents. 2) Define groups of agents with similar behaviour towards the solvents. 3) Detect possible correlations between groups of solvents and of protective agents. 4) Order the protectives in a sequence reflecting their solubility towards the entire complex of solvents.

The dendrogram of the solvents is shown in Fig. 1. By cutting the dendrogram at a value of Correlation Coefficient of - 0.88, four main clusters are formed, as follows:

Cluster 1) includes Paraffins, Cycloparaffins and Olefins
Cluster 2) includes mainly aromatic and chloro-compounds
Cluster 3) includes alcohols, acetone, and compounds with nitrile groups.
Cluster 4) includes only water.

The dendrogram of the protectives is shown in fig. 2. Three main clusters are formed, as follows:

Cluster A: includes 16H6F and syloxane
Cluster B: includes all the cross-linked resins: Polyuretanic,. acrylic and epoxydic.
Cluster C: includes all the perfloro-compound: Crytox AX, Fomblin, Galden and Fomblinammide.

The correlation betweens groups of protective agents and solvents are shown in Fig. 3 and 4 (a, b) which report the position of the solvents (Fig. 4a) and of the protective agents (Fig. 4b) in the space defined by the two canonical variates of the reciprocal ordering. Fig. 3 has been obtained by centering the ordination on the similarity matrix of the protectives, Fig. 4 on the matrix of the solvents.

In Fig. 3 the protectives are disposed according to a horse-shoe at whose extremes are disposed Fomblin and 16H6F. This arrangement corresponds with a gradient of increasing inertia towards the solvents. This is evident in Fig. 5, where the x-axis reports the angular seriation of the protectives in Fig. 3, and the y-axis

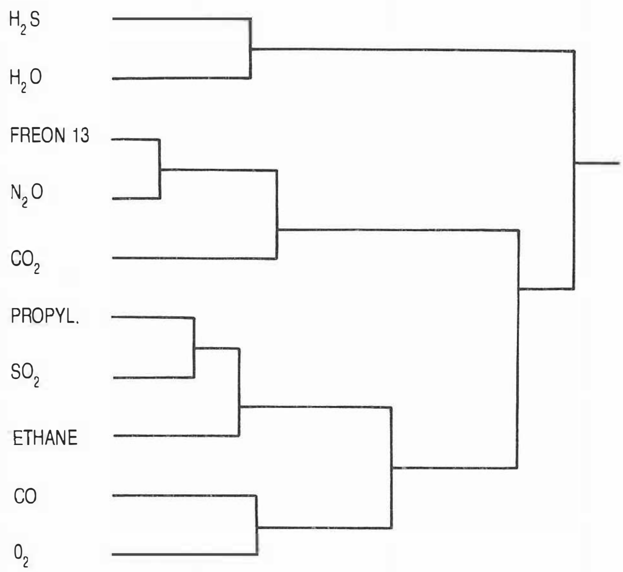


Fig. 8 - Dendrogram of the gases, obtained on the basis of the data of Tab. 2.



Fig. 9 - Dendrogram of the protective agents, obtained on the basis of the data of Tab. 2.

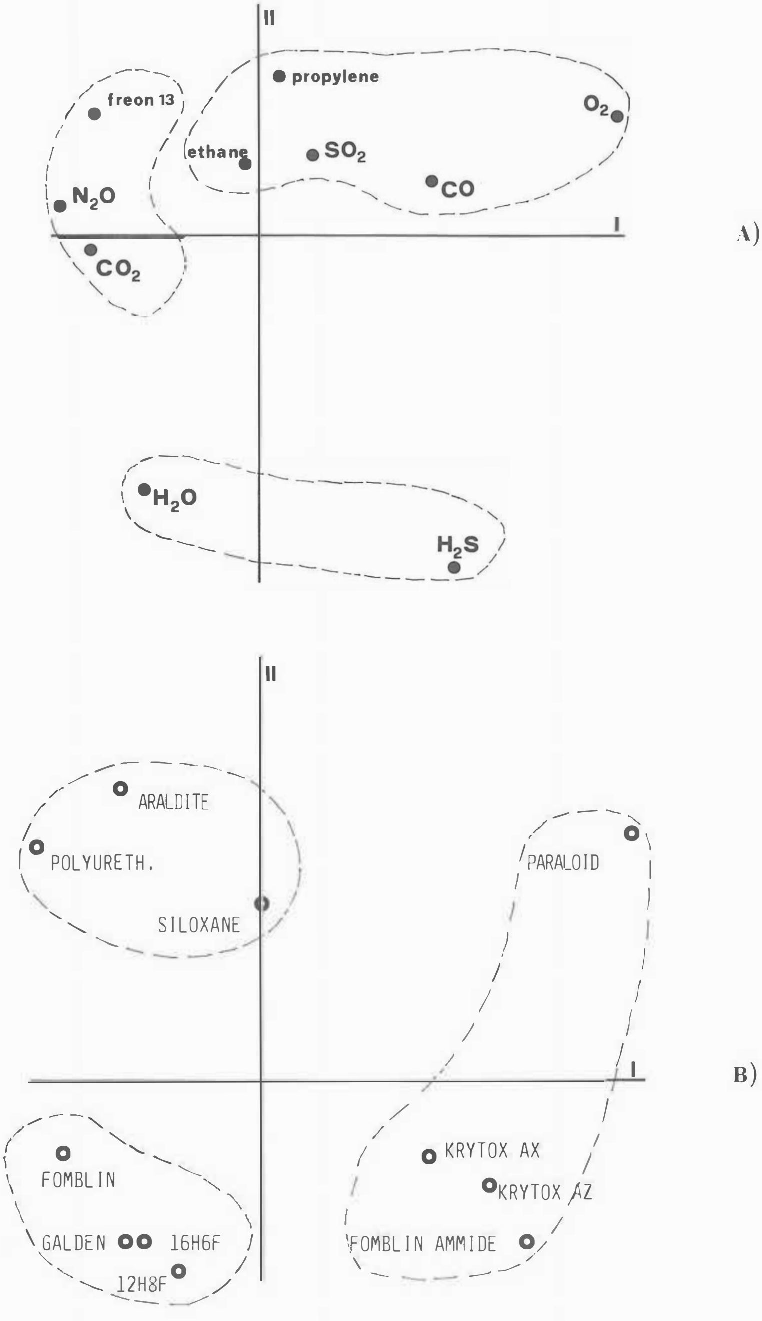


Fig. 10 - Reciprocal ordering of gases (a) and protective agents (10b), based on the data of Tab. 2.

expresses an index of inertia obtained by averaging the values of Henry's Constants of each solvent in each protective.

In Fig. 4a the solvents are disposed according to an horse-shoe corresponding to a polarity gradient, as shown by Fig. 6, where the x-axis reports the angular seriation of solvents in Fig. 4a, and the y-axis expresses Hildenbrand's constants. Fig. 4b shows the reciprocal ordination of protectives corresponding to that of the solvents in Fig. 4a. Their angular seriation, starting from Paraloid and Poliuretane to the Siloxane, corresponds to a gradient of increasing affinity for polar compounds. Fig. 7 shows the correlation between the two ordinations of protectives (Figg. 3 and 4 b): there is a negative correlation between the affinity for polar compounds and chemical inertia, with the exception of Siloxane and 16H6F, whose molecule has paraffinic part and a part with high chemical inertia (silica and fluoro), and which differ from the others by a far smaller molecular weight.

Tab. 2 reports the solubility of 10 gases in 11 protectives. Ordination and classification programs were also used to analyze these data: both dendrograms (gases and protectives) allow to distinguish three main groups, which are shown in Fig. 8 (protectives) and 9 (gases). The relations between gases and protectives have been studied by reciprocal ordering. The results are shown in Fig. 10a (gases) and 10b (protectives). The group B of protectives is very inert towards water and H_2S; the group C is highly soluble in H_2S and in water, with synergic effects, but has a high inertia towards the other pollutants. In the ordination, the group B of protectives is dismembered: the Paraloid assumes an isolated position; this compound has a negative behaviour towards all gases, and the highest solubility towards water; the other members of cluster B have an inertia similar to the one of the other perfluoro-compounds, with the exception of a higher inertia towards H_2S.

Conclusions

These results may be a first information basis for further biological studies aiming at analyzing the micropedogenetic phenomena occurring on rock surfaces treated with protectives. In particular, a possible line of research, that can be carried out both in the laboratory and in the field, could be the comparative study of a few protective substances, one for each of the main groups discussed above. These groups have a different behaviour in respect with water and the main athmospheric pollutants, and probably should host different micropedogenetical processes. In any case, before starting a study on a single treated stonework one can refer to the group in which the protective is included, to get additional information which could allow a correlation between biological results and the main chemical properties of the new substrate.

References

Anderberg M.R., 1973. *Cluster Analysis for Applications.* Accademic Press. New York.

Banks R.E., 1974. *Fluorocarbons and their derivatives.* Olbourne Press. London.

Biscontin G., Botteghi C., Dalla Vecchia C., Driussi G., Moretti G. & A. Valle, 1986. *Studio di stabilità di resine siliconiche impiegate nella conservazione dei materiali lapidei.* Atti Congr., Bressanone.

Carrol D., 197●. *Rock wheathering.* Plenum Press, New York.

Guidotti G.R., 1985. *Ruolo dell'inquinamento atmosferico nel degrado delle opere d'arte.* Acqua-Aria.

Laub J.R. & R.L. Pecsok, 1978. *Physico-chemical Applications of Gas Chromatography.* Wiley & So., New York.

Lazzarini L. & M. Laurenzi-Tabasso, 1986. *Il restauro della pietra.* Cedam. Padova.

Marinelli G., 1975. *L'impiego di una resina epossidica alifatica nel consolidamento di materiali da costruzione porosi di scadenti caratteristiche meccaniche.* Simp. Intern. Conserv. della Pietra. Bologna.

Orloci L., 1978. *Multivariate Analysis in Vegetation Science.* 2nd ed. Junk. The Hague.

Pasetti A., 1984. *Fomblin Y Met: un nuovo protettivo corticale.* Atti Conv. "Riabitat". Ed. Sagep. Genova.

Piacenti R., Matteoli U., Tiano P., Manganelli Del Fà C., Fratini F. & A. Scala, 1985. *New protective agents for stone materials.* V. Congr. Int. Deterior. and Conserv. of Stone. Lausanne.

Savoye D. & R. Lallemant, 1979. *Evolution de la microflore d'un substrat avant et pendant sa colonisation par les Lichens. I. Le cas de toitures and amiante-ciment en zone suburbaine.* Rev. Bryol. Lichenolol.

Wildi O. & Orloci, 1983. *Management and multivariate analysis of vegetation data.* Swiss. Fed. Inst. For. Res.. Birmensdorf.

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AZIONE DELLE CRESCITA DEI LICHENI SULLA PIETRA NELL'AREA ARCHEOLOGICA DI FIESOLE

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Keywords: Archaeological area, Fiesole, Italy, Lichens, Stone alteration.

Abstract. The archaeological area in Fiesole, where a local sandstone (Pietra Serena) was mainly used, was taken into consideration with the purpose of investigating the mechanical and chemical alteration possibly due to lichen growth.

The taxonomic data allowed identification of almost 40 species. Distribution data allowed definition and localization of the most frequent species, therefore permitting a choice of those to be taken into consideration in relation to their effect on the stone. Observation of stone specimens under optical and scanning electron microscopes showed the morphology of mechanical alterations caused by the growth of some lichen species. The map of distribution of calcium determined by analysis carried out under SEM equipped with an energy dispersive X-ray spectrometer (EDS) showed that some species cause modification of the mineralogical stone composition. Moreover, analyses by X-ray diffractometry, in connection with the above results, allow the identification of the production of calcium oxalate due to the growth of some species.

Introduzione

Il deterioramento della pietra ad opera dei licheni è stato studiato finora in modo piuttosto frammentario.

È noto che molte specie licheniche possono essere causa di danni di tipo meccanico dovuti alla penetrazione del tallo in profondità ed alle espansioni e contrazioni che esso subisce in funzione delle variazioni climatiche (Fry, 1927). Secondo Ozenda e Clauzade (1970) tali danni non sarebbero però molto seri data la lenta crescita di questi vegetali.

È stato oggetto di studio anche il deterioramento chimico della pietra causata dai licheni, più precisamente dagli acidi (prodotti del loro metabolismo) che possono complessare elementi chimici contenuti nella roccia (Schatz, 1963; Iskandar e Syers, 1972; Ascaso et al, 1976; Purvis et al, 1987; Lounamaa, 1965). Tuttavia alcuni autori ritengono che, nei casi in cui la crescita dei licheni sia limitata, questi vegetali possono formare un rivestimento protettivo efficace a limitare l'azione di altri agenti di degrado (Lallement et Deruelle, 1978).

Nell'ambito della problematica sopra esposta abbiamo scelto come oggetto di

studio i monumenti dell'area archeologica di Fiesole, che appaiono estesamente ricoperti di licheni. I risultati ottenuti sono oggetto di questa nota.

L'indagine è stata limitata alle specie più frequenti e si poneva lo scopo di valutare i danni meccanici e chimici da esse eventualmente provocati nei vari substrati lapidei qui presenti: Pietra Serena, marmo, laterizi e anche intonaci.

Descrizione dell'area archeologica

L'area archeologica di Fiesole include tre strutture monumentali distribuite su una superficie piuttosto vasta: il Tempio Etrusco (III sec. A.C.), le Terme e il Teatro Romano (entrambi del I sec A.C.). I monumenti sono stati scavati in tempi diversi ma, agli inizi di questo secolo, l'area archeologica corrispondeva a grandi linee a quella attuale (Caputo e Maetzke, 1959).

Essa è situata nella valle del fiume Mugnone, in un ambiente seminaturale collinare con poche case sperse e limitata a Sud dall'abitato di Fiesole.

Tutti i tre monumenti fiesolani sono stati oggetto della nostra indagine volta a definire il deterioramento dei materiali lapidei causato dalla crescita di licheni. I risultati relativi al Teatro Romano sono già stati pubblicati (Pallecchi e Pinna, 1988). La presente nota riguarda il Tempio Etrusco e le Terme Romane. Tali strutture monumentali sono entrambe costruite con blocchi squadrati di arenaria locale ("Pietra Serena"), una grovacca feldspatica a matrice argillosa con scarsa calcite (valore medio 7%) interstiziale e solo raramente spatica (Malesani e Vannucci, 1974).

La stessa Pietra Serena è stata utilizzata per strutture di recente costruzione, elevate nel corso dei restauri del 1953.

Nelle Terme oltre alla Pietra Serena, vi sono strutture in laterizio, solo in parte originarie; tra queste ultime, quelle del Frigidarium e quelle delle Sospensurae del Calidarium (Fig. 1) (costruite con mattoni ottagonali).

Oltre a mattoni e Pietra Serena, i materiali presenti nell'area considerata, e quindi presi in considerazione in relazione al fenomeno della crescita lichenica, sono il marmo cristallino con cui sono rivestiti due basamenti di Pietra Serena accanto al Tempio e poi gli intonaci, quelli a calce, originali, ancora estesamente presenti e quelli a cemento dei rifacimento del 1953 (Bellini Delle Stelle et al, 1984).

Procedimenti sperimentali

I campioni di licheni sono stati prelevati nell'area in esame annotando contemporaneamente sia il tipo di substrato che eventuali differenze, quali esposizione, entità della copertura lichenica, ecc., che caratterizzavano la zona di prelievo. Le specie licheniche sono state identificate con le metodologie standard. I risultati, in relazione al tipo di substrato, sono riportati in Tabella 1.

Per lo studio degli effetti della crescita dei licheni sul substrato, sono state prese in considerazione alcune delle specie risultate più diffuse sulle strutture originarie: *Aspicilia hoffmannii*, *Diploschistes actinostomus*, *Pertusaria amara*,

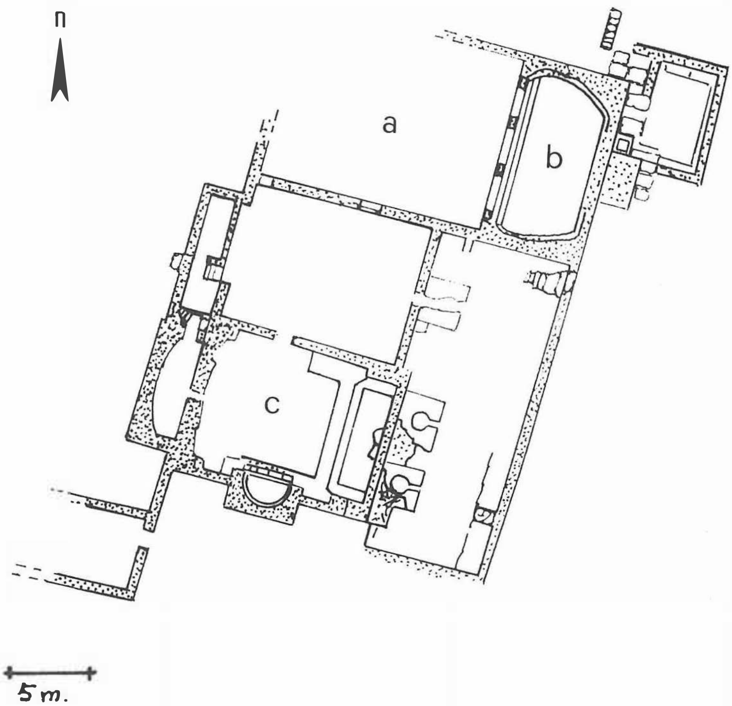


Fig. 1 - Le Terme Romane di Fiesole
a: Frigidarium; b: Piscina di acqua fredda; c: Calidarium

Tephromela atra (arenaria), *Lecanora muralis* (marmo e arenaria), *Lecidella stigmatea* (laterizi), *Verrucaria nigrescens* (marmo, intonaco e arenaria), *Xantoria elegans* (marmo). Alcune di qeuste specie *(Aspicilia hoffmannii, Diploschistes actinostomus, Tephromela atra)* sono già state prese in considerazione in occasione dello studio degli effetti della loro crescita sulla Pietra Serena del Teatro Romano (Pallecchi e Pinna, 1988).

Sono state preparate sezioni trasversali dei campioni, includenti oltre al lichene anche parte del materiale sottostante, per poter osservare l'interazione tra il tallo e il substrato su cui questo attecchisce.

Gli aspetti morfologici dell'interazione tallo-substrato sono stati osservati al microscopio elettronico a scansione (SEM) Philips 505. Per lo studio delle variazioni composizionali del substrato attribuibili alla crescita lichenica, sono state eseguite analisi per spettrometria di raggi X in dispersione di energia (EDS) sulle sezioni stesse, utilizzando il sistema microanalitico EDAX unito al SEM.

Frazioni dei campioni (tallo + substrato sottostante) sono state polverizzate in mortaio di agata e analizzate per diffrattometria ai raggi X (diffrattometro Philips 1840 con anticatodo in rame - CuKα) per identificare i minerali presenti.

Tabella 1: Distribuzione delle specie nel Tempio Etrusco e nelle Terme Romane (le specie presenti occasionalmente non sono state riportate)
S = scarso; M = medio; A = abbondante

	TEMPIO			TERME		
	arenaria	**intonaco**	**marmo**	**arenaria**	**intonaco**	**laterizi**
Aspicilia calcarea (L.) Mudd				S	S	
Aspicilia contorta (Hoffm.) Krempelh.	S		S			
Aspicilia hoffmannii (Ach) Flag.	M	S	S	S	S	
Buellia ambigua (Ach.) Malme				M		S
Caloplaca citrina (Hoffm.) Th. Fr.	S			S	S	
Caloplaca crenularia (With.) Laund.	M			A	M	
Caloplaca teicholyta (Ach.) Steiner	S					
Candelariella vitellina Mull. Arg.	M			M	S	
Collema tenax (Swartz) Ach. em. Degel.	S					
Dermatocarpon miniatum (L.) Mann				S		
Diploicia canescens (Dicks.) Massal.	M	S				
Diploschistes actinostomus (Pers.) Zahlbr.	M			M	M	
Diploschistes muscorum (Scop.) R. Santesson	M					
Diploschistes scruposus (Schreber) Norm.	M					
Lecania erysibe (Ach.) Mudd s. lat.	S					S
Lecanora albescens (Hoffm.) Flörke						S
Lecanora campestris (Schaer.) Hue				S		
Lecanora dispersa (Pers.) Sommerf.	S			M	S	S
Lecanora muralis (Schreb.) Rabenh.	A	S	A	S	M	
Lecidea fuscoatra (L.) Ach.	S	S		M	M	
Lecidella stigmatea (Ach.) Hertel et Leuck.	M			M		S
Lepraria incana (L.) Ach.				S		
Ochrolechia parella (L.) Massal.	M					
Parmelia conspersa Ach.	M					
Parmelia loxodes Nyl.	A					
Parmelia tiliacea (Hoffm.) Ach.	A					
Pertusaria amara (Ach.) Nyl.	S					
Physcia adscendens (Fr.) H. Olivier	S		M			
Physcia biziana (Massal.) Zahlbr.	S			M		
Physcia orbicularis (Necker) Poetsch.	S					
Placynthium nigrum (Hudson) Gray				M		
Scoliciosporum umbrinum (Ach.) Arnold	M			M		
Tephromela atra (Huds.) Hafellner	M			M	M	
Verrucaria nigrescens Pers.	M	M	M	M	M	
Xanthoria elegans (Link) Th. Fr.			M	S		
Xanthoria parietina (L.) Th. Fr.	S					

Risultati

Distribuzione delle specie

Tempio Etrusco

La crescita dei licheni è piuttosto uniforme e generalmente abbondante su tutta l'area del Tempio. Predominano nettamente le specie crostose, ma in alcune zone (ad es. sulle pareti verticali dei gradini della scalinata) si osserva un buon sviluppo di specie foliose (v. Tab. 1).

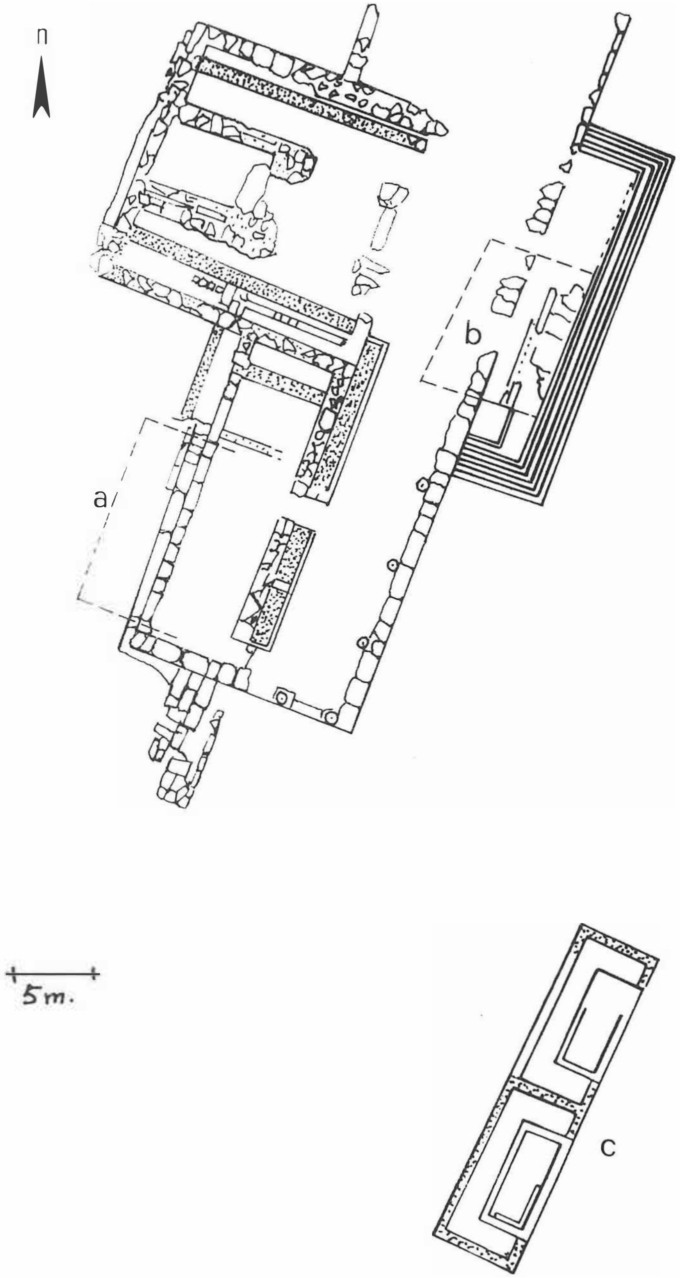


Fig. 2 - Il Tempio Etrusco di Fiesole
a: parete del 1953 in Pietra Serena e intonaco; b: zona scavata (1954-62) dopo la stesura della carta topografica (1953); c: basamenti in Pietra Serena con lastroni di marmo.

Le indicazioni di Wirth (1980) sugli indici di tolleranza delle singole specie nei confronti di specifici paramentri ambientali offrono utili notizie sull'ecologia della zona. Ad eccezione di *Lecanora dispersa, Physcia adscendens* e *P. orbicularis*, la maggior parte delle specie presenti è moderatamente nitrofitica; se ne può dedurre che l'eutrofizzazione (apporto di polvere e nitrati) nella zona è a livelli piuttosto bassi.

Inoltre le specie presenti sono in maggioranza fotofitiche, tollerano cioè un grado di luminosità piuttosto elevato.

L'abbondante sviluppo di licheni generalmente osservato non si riscontra sulla superficie della parete più esterna a sinistra della cella (Fig. 2). Tale parete, rifatta nel 1953, è ricoperta con intonaco a base di cemento. Escludendo diversità microclimatiche rispetto alle aree circostanti, si possono ipotizzare due possibili cause di questo modesto sviluppo lichenico: 1) l'età piuttosto recente del muro; 2) il diverso tipo di substrato, l'intonaco a cemento, che potrebbe influenzare lo sviluppo delle specie. Quest'ultima ipotesi può risultare avvallata dal fatto che sugli scalini di Pietra Serena antistanti la cella riportati alla luce durante la campagna di scavo del 1954-62 si osserva invece un discreto sviluppo lichenico. Per quanto riguarda l'esposizione all'atmosfera e quindi l'inizio della colonizzazione dei licheni, gli scalini di Pietra Serena e l'intonaco a cemento sono coevi: si può forse concludere che la Pietra Serena è un materiale più favorevole alla crescita dei licheni dell'intonaco cementizio.

Sui lastroni di marmo che in parte ancora rivestono i basamenti in Pietra Serena (di età Romana) in prossimità del Tempio Etrusco lo sviluppo dei licheni non è molto abbondante, molto meno abbondante che sulla Pietra Serena contigua (dove il rivestimento marmoreo non esiste più). Sul marmo si osserva però la crescita di *Xanthoria elegans*, specie quasi del tutto assente sugli altri materiali.

Terme Romane

Nelle Terme Romane lo sviluppo dei licheni è discontinuo e meno abbondante che nel Tempio Etrusco. L'unica area dove la crescita è discreta è quella dei ruderi della piscina di acqua fredda accanto al Frigidarium (Fig. 1). Le pareti di arenaria della piscina sono in più zone ancora intonacate (l'intonaco è probabilmente originario). Lo sviluppo dei licheni è notevole sia sull'arenaria che sull'intonaco.

Salvo l'eccezione della piscina di acqua fredda, la crescita dei licheni è in generale assai più limitata che nel Tempio e nel Teatro; il fenomeno può essere in parte dovuto alle condizioni ambientali, giacchè il monumento è addossato su due lati (Sud ed Est) alla collina e presenta alcune pareti quasi costantemente in ombra.

L'eutrofizzazione, nella zona delle Terme, deve essere modesta come nel caso del Tempio: la maggior parte delle specie è infatti moderatamente nitrofitica. I licheni trovati sono inoltre per lo più fotofitici.

Effetti sui materiali lapidei

L'indagine microanalitica ha mostrato un diverso effetto delle specie liche-

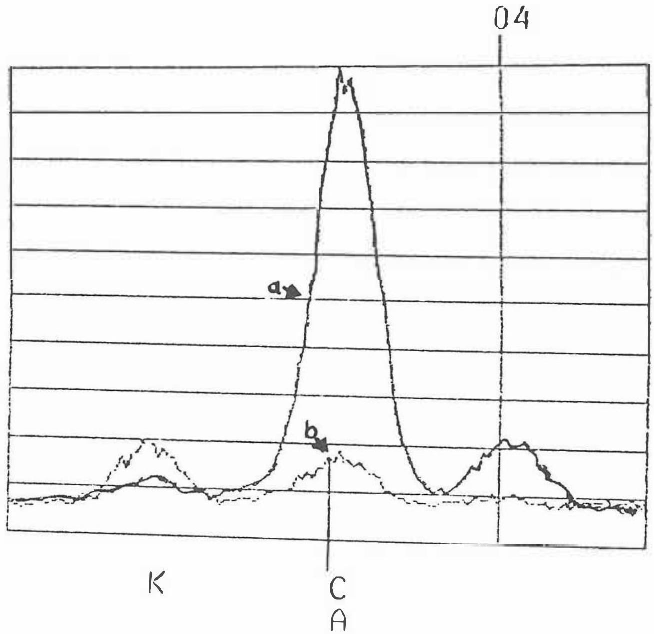


Fig. 3 - Spettro EDS di Ca e K nel tallo (a) di *Aspicilia hoffmannii* e nella Pietra Serena (b) sulla quale cresce.

niche studiate.

La crescita su arenaria di *Aspicilia hoffmannii*, *Diploschistes actinostomus*, *Pertusaria amara* e *Tephromela atra* e la crescita sul marmo di *Xanthoria elegans* provocano modificazioni chimiche nel substrato. Il contenuto di Calcio è infatti maggiore entro il tallo che nella zona del substrato interessata dalla penetrazione delle ife (Fig. 3, 4, 5), mentre gli elementi Si, K, Fe, Al sono presenti nel tallo generalmente in quantità minori che nei substrati lapidei. Un'eccezione è costituita da un campione di *Aspicilia hoffmannii* e da uno di *Diploschistes actinostomus* il cui contenuto di Ferro è in quantità leggermente maggiore entro il tallo che nel substrato.

Inoltre l'analisi per diffrattometria RX ha mostrato che il tallo di tutte le specie sopra elencate contiene ossalati di Calcio.

Diverse sono le conseguenze della crescita di altre specie: *Lecanora muralis* (su marmo e arenaria) e *Verrucaria nigrescens* (su intonaco, marmo e arenaria). In questi casi si osservano soltanto modeste variazioni composizionali in un sottile strato superficiale dei substrati (subito sotto ai licheni) dove si evidenzia una piccola diminuzione del Calcio.

Il contenuto di questo elemento evidenziato per analisi EDS può corrispondere ad ossalato di Calcio identificato però, per diffrattometria RX, soltanto in tracce nel tallo di *Lecanora muralis* sul marmo.

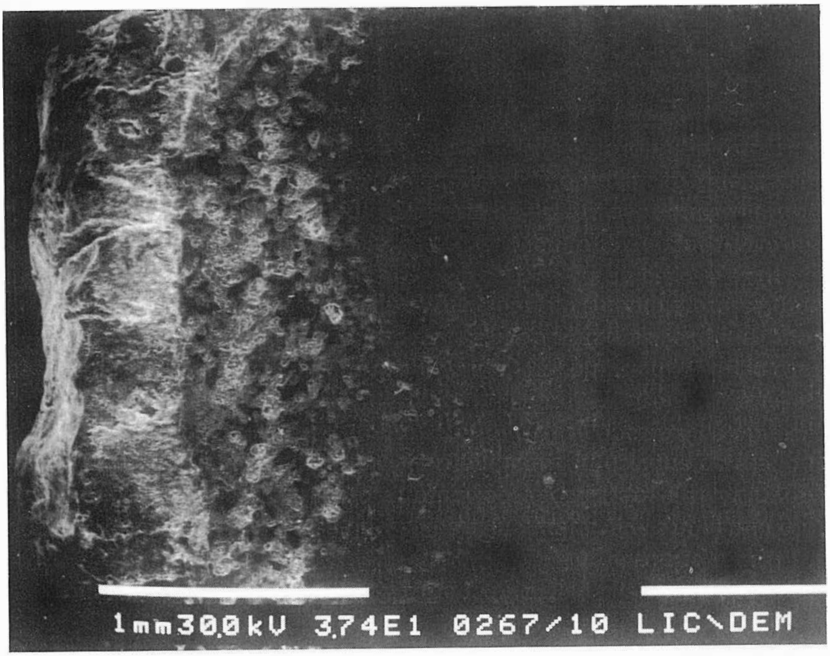


Fig. 4 - Microfotografia al SEM di *Aspicilia hoffmannii* su Pietra Serena (Tempio Etrusco).

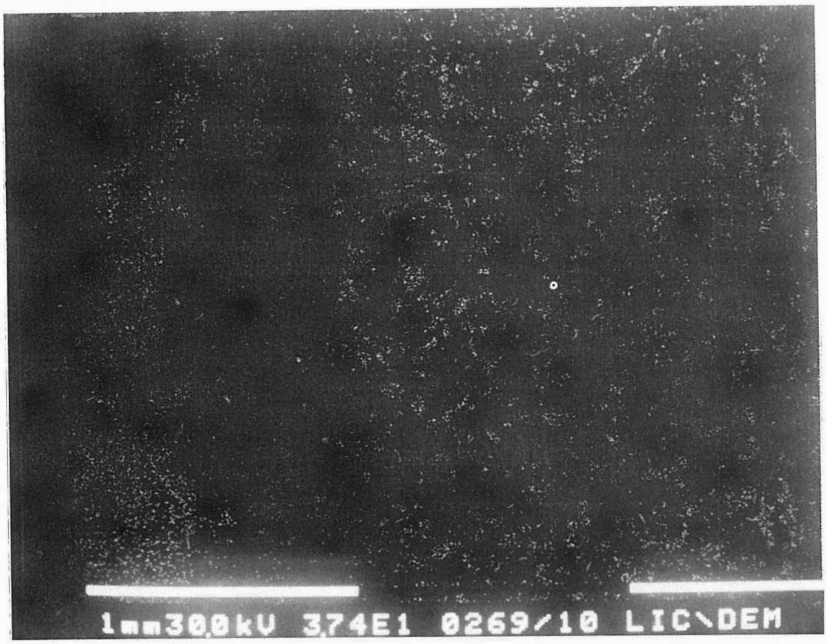


Fig. 5 - Mappa di distribuzione del Calcio corrispondente alla Fig. 4. Si possono riconoscere le regioni ricche di Calcio all'interno del tallo.

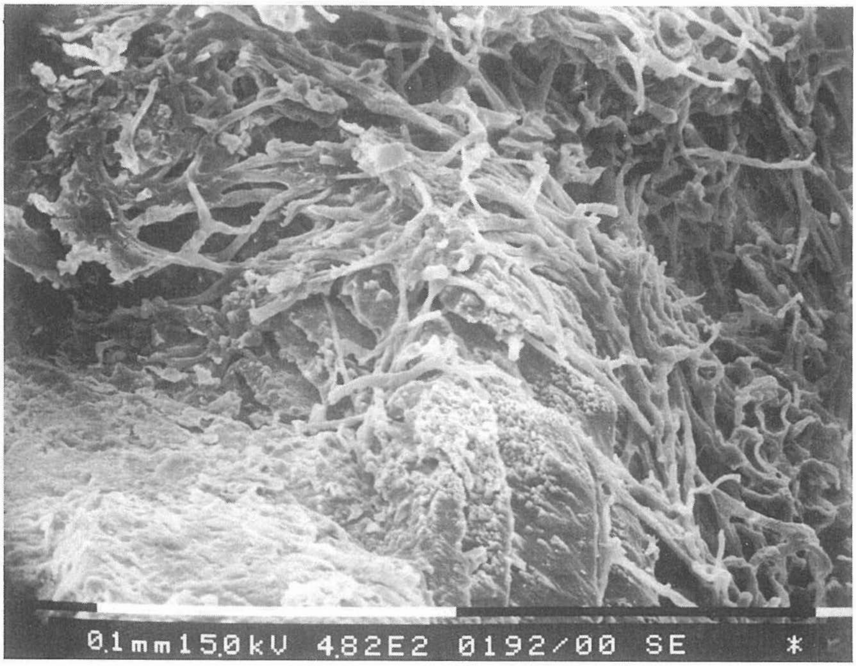


Fig. 6 - Microfotografia al SEM di *Xanthoria elegans* sul marmo. Le ife inglobano un clasto del substrato. Profondità 1 mm.

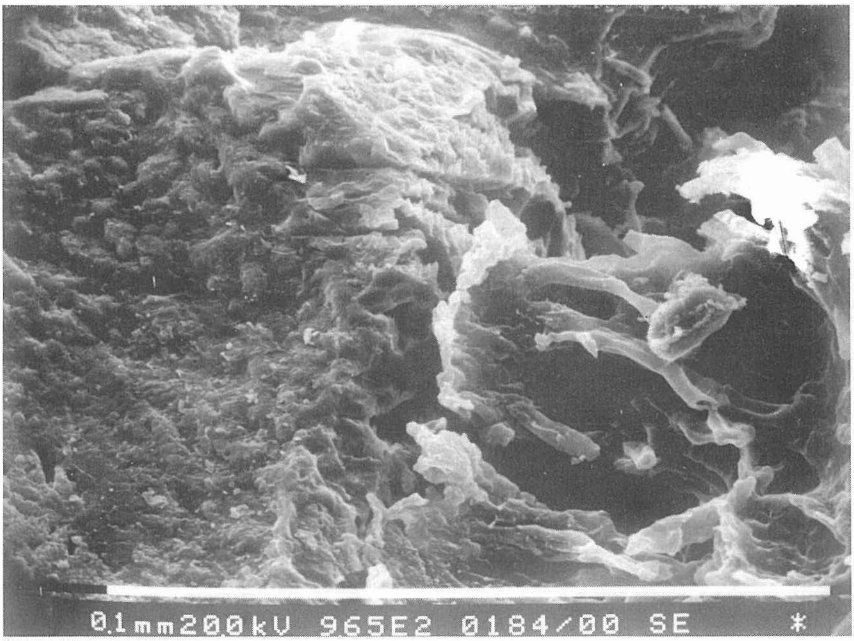


Fig. 7 - Microfotografia al SEM di *Xanthoria elegans* sul marmo. Ife a contatto con il substrato. profondità 1 mm.



Fig. 8 - Microfotografia al Sem di *Verrucaria nigrescens* su intonaco. Profondità 1 mm.

La crescita inoltre di *Lecidella stigmatea* su laterizi non produce apprezzabili modificazioni chimiche sul substrato.

L'osservazione morfologica al SEM di tutte le specie insieme al relativo substrato, in sezione, ha fornito i seguenti risultati: *Aspicilia hoffmannii, Diploschistes actinostomus, Pertusaria amara, Tephromela atra* e *Xanthoria elegans* (Fig. 6, 7) penetrano entro tutti i relativi substrati fino ad una profondità di 2 mm; *Lecanora muralis* e *Verrucaria nigrescens* (Fig. 8) penetrano fino a 1.5 mm; *Lecidella stigmatea* penetra fino a 0.5 mm. Si evidenzia inoltre chiaramente che l'azione meccanica delle ife penetranti provoca una modificazione della struttura originale della pietra.

Conclusioni

L'area comprendente le Terme Romane e soprattutto il Tempio Etrusco rappresenta, analogamente a quanto già osservato nel Teatro Romano (Pallecchi e Pinna, 1988), un ambiente idoneo allo sviluppo di molte specie licheniche.

I substrati più favorevoli alla crescita risultano essere la Pietra Serena e gli intonaci a base di calce, mentre il marmo e i laterizi presentano uno sviluppo piuttosto scarso.

La colonizzazione lichenica, oltre a provocare variazioni cromatiche delle strutture, ha conseguenze di tipo meccanico e chimico sul substrato.

Dagli esami analitici risulta che *Aspicilia hoffmannii, Diploschistes actinostomus, Pertusaria amara* e *Tephromela atra* sull'arenaria e *Xantoria elegans* sul marmo hanno sottratto il Calcio alla pietra concentrandolo nel tallo. Le stesse specie sono, tra tutte quelle studiate, le uniche che contengono entro il tallo discrete quantità di ossalati di Calcio, composti che possono derivare dalla reazione tra il Calcio e l'acido ossalico prodotto dai licheni (Wadsten e Moberry, 1985). Le stesse specie penetrano all'interno dei materiali lapidei fino a 2 mm.

L'effetto sulla Pietra Serena di alcune di queste specie (*Aspicilia hoffmannii, Diploschistes actinostomus, Tephromela atra*) è già stato studiato a proposito del Teatro Romano (Pallecchi e Pinna, 1988) e i risultati ottenuti corrispondevano a quelli sopradescritti. Se ne può dedurre che le strutture in Pietra Serena e le condizioni ambientali dell'intera area archeologica sono particolarmente adatte alla crescita di queste tre specie, le quali, a loro volta, sono tra quelle che producono i maggiori danni al materiale lapideo.

Per quanto riguarda le altre specie studiate (*Lecanora muralis* su marmo e arenaria, *Verrucaria nigrescens* su intonaco, marmo e arenaria) è da rilevare che, mentre il danno chimico che esse provocano è di modesta entità, il danno meccanico può essere più grave: tali specie penetrano all'interno dei materiali fino a 1.5 mm, provocando fratture e dislocazioni dei componenti cristallini dei substrati.

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Bibliografia

Ascaso C., Galvan J. e Ortega C., 1976. *The pedogenic action of Parmelia conspersa, Rhizocarpon geographicum and Umbilicaria pustulata.* Lichenologist, 8: 151-171.

Bellini Delle Stelle F., Mannari A. e Sabelli R., 1984. *Le Terme Romane di Fiesole.* Comune di Fiesole.

Caputo G. e Maetzke G., 1959. *Presentazione del rilievo di Fiesole Antica.* Studi Etruschi, 27: 41-49.

Fry E.J., 1927. *The mechanical action of crustaceous lichens on substrata of shale, schist, gneiss, limestone and obsidian.* Annals of Botany, 41: 437-460.

Iskandar I.K. & Syers J.K., 1972. *Metal-complex formation by lichen compounds.* J. Soil Sci., 23: 255-265.

Lallement R. & Deruelle S., 1978. *Presence de lichens sur les monuments en pierre. Nuisance ou protection.* International Symposium UNESCO-RILEM: Deterioration and protection of stone monuments, Parigi, Vol. II.

Lounamaa K.J., 1965. *Studies on the content of iron, manganese and zinc in macrolichens.* Ann. Bot. Fenn., 2: 127-137.

Malesani P.P. e Vannucci S.A., 1974. *Decay of Pietra Serena e Pietraforte, Florentine building stones: petrographic observations.* Studies in Conservation, 19 (1): 36-49.

Ozenda P. & Clauzade G., 1970. *Les Lichens.* Masson. Paris.

Pallecchi P. & Pinna D., 1988. *Alteration of stone caused by lichen growth in the Roman Theatre of Fiesole (Firenze).* 6th International Congress on Deterioration and Conservation of Stone, Torun. Preprints (in corso di stampa).

Purvis O.W., Elix J.A., Broomhead J.A. e Jones G.C., 1987. *The occurence of copper norstictic acid in lichens from cupriferous substrata.* Lichenologist, 19 (2): 193-203.

Schatz A., 1963. *The importance of metal-binding phenomena in the chemistry and microbiology of the soil. Part I: The chelating properties of lichens and lichen acids.* Advancing Frontiers of Pl. Sci., 6: 113-134.

Wadsten T. e Moberry R., 1985. *Calcium oxalate hydrates on the surface of lichens.* Lichenologist, 17 (3): 239-245.

Wirth V., 1980. *Flechtenflora.* Ulmer, Stuttgart.

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I LICHENI ENDOLITICI CALCICOLI SU MONUMENTI

P.L. NIMIS, L. ZAPPA

Keywords: Endolithic, Lichens, Limestone, Monuments.

Abstract: ENDOLITHIC LICHENS ON LIMESTONE MONUMENTS - This paper briefly illustrates the main features of endolithic lichens growing on limestone, with particular regard to some species which have been found growing on monuments. The action of endolithic lichens on stone is also discussed, with some remarks on the possible harmful effects of the application of biocides to remove endolithic lichens from monuments.

Introduzione

Gli operatori che si occupano della manutenzione e del restauro di monumenti in pietra calcarea tendono spesso a fissare l'attenzione sui licheni epilitici nitrofili. Il motivo è che queste forme sono molto evidenti e spesso vivacemente colorate, per cui determinano una forte alterazione cromatica delle superfici litiche. Tra le specie più appariscenti si possono annoverare *Xanthoria calcicola, Candelariella medians, Caloplaca citrina, C. flavescens, C. aurantia,* etc.

Esiste però un secondo gruppo di licheni calcicoli, il cui tallo è profondamente infossato nella roccia: si tratta dei licheni cosiddetti "endolitici", in genere molto meno vistosi di quelli epilitici, anche perché il colore del tallo è spesso simile a quello del substrato. Questi organismi appartengono in gran parte ai licheni pirenocarpi, a quelli cioé il cui corpo fruttifero è un peritecio; i generi più frequenti su monumenti sono *Bagliettoa, Verrucaria, Porina* ed *Acrocordia.* Esistono comunque anche licheni endolitici discocarpi, quali *Rinodina immersa,* alcune *Protoblastenia, Clauzadea, Caloplaca* etc.

In genere questi licheni sono non o poco nitrofili e relativamente sciafili. Per questo motivo occupano spesso le parti basali dei monumenti con esposizione a settentrione. Rispetto ai licheni epilitici nitrofili quelli endolitici hanno esigenze ecologiche più ristrette, essendo più frequenti su calcari porosi quali il travertino, molto più rari su rocce carbonatiche dure e a grana cristallina quali il marmo.

Tra i licheni crostosi epilitici e quelli endolitici il passaggio non è sempre netto:

esistono forme a tallo parzialmente endolitico (licheni emiendolitici), in cui il tessuto pseudocorticale e lo strato gonidiale sono siti sopra la superficie litica; mentre esiste una zona rizoidale, costituita da ife fungine, che penetra più o meno profondamente nella roccia.

Gli studi effettuati da Giacobini et al. (1979, 1987) hanno dimostrato come il trattamento con biocidi di superfici litiche attaccate da licheni non sempre permette di ottenere risultati soddisfacenti; in particolare, i talli endolitici sono i più refrattari al trattamento. A questo va aggiunto che l'asporto di licheni endolitici con mezzi puramente meccanici è in genere di difficile attuazione, in quanto comporta l'abrasione dello strato superficiale della roccia permeato dalle ife del lichene. Per questo motivo il trattamento a scopo restaurativo-conservativo di superfici litiche attaccate da licheni endolitici risulta particolarmente problematico.

Lo scopo di questo lavoro è duplice: da un lato si vuole fornire una prima base di informazioni utili ad orientare gli operatori del settore nel trattamento di monumenti attaccati da licheni endolitici calcicoli, dall'altro si intendono sottolineare una serie di problemi aperti che richiedono ulteriori ricerche di base.

Materiali e metodi

Per illustrare questo lavoro sono stati analizzati campioni di tre specie di licheni endolitici calcicoli: *Bagliettoa parmigerella*, *Bagliettoa parmigera* e *Caloplaca ochracea*, quest'ultima probabilmente ha tallo emiendolitico.

Ciascun campione è stato sottoposto a tre diverse indagini:

1 - Osservazione al microscopio stereoscopico di frammenti calcarei ricoperti da licheni.

2 - Osservazione al microscopio metallografico.

I frammenti di roccia sono stati preventivamente inclusi in resina e successivamente levigati in modo da ottenere una superficie perfettamente piana con il lichene in sezione trasversale. Questa tecnica consente di valutare la posizione del tessuto pseudocorticale e dello strato algale rispetto alla superficie della pietra, la profondità cui possono arrivare le ife fungine e la loro organizzazione reale all'interno della roccia.

3 - Osservazione al microscopio ottico di talli decalcificati.

La preparazione di sezioni sottili di talli endolitici è praticamente impossibile se non si allontana tutto il substrato calcareo in cui è immerso il lichene. Nel caso specifico è stata usata una soluzione al 3% di HCl (Fry, 1922) in cui sono stati immersi i frammenti calcarei. Terminata la decalcificazione i talli sono stati fissati ed inclusi in una resina idrosolubile e quindi sono state fatte sezioni sottili di 5-7 micron. Per aumentare il contrasto le sezioni sono state trattate con coloranti aspecifici (Blu di toluidina, Violetto cresile e colorazione PAS positiva).

Struttura del tallo dei licheni endolitici calcicoli

La morfologia dei licheni endolitici è stata oggetto di un dettagliato studio da

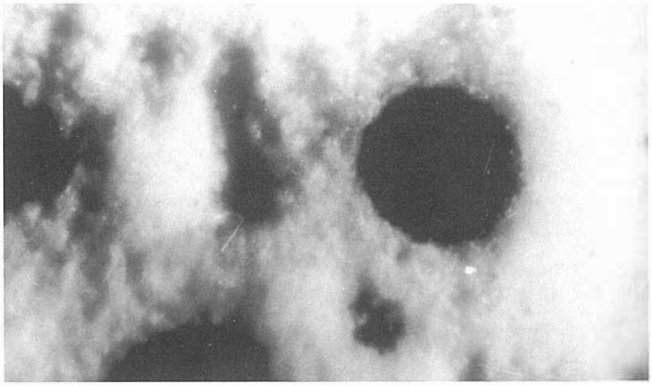


Foto 1 - Periteci di *Bagliettoa parmigera*, ingrandimento 85 X.

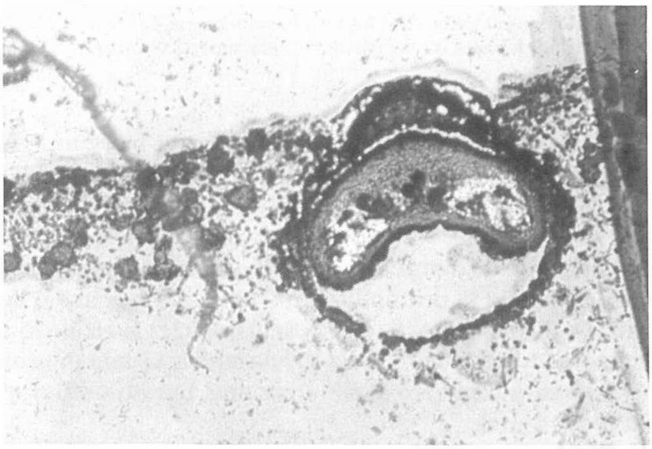


Foto 2 - Peritecio di *Bagliettoa parmigerella*, ingrandimento 400 X.
Sezione sottile di tallo decalcificato, colorata con violetto cresile.
Ben visibile la struttura del tallo lichenico, con le ife più fitte nella parte superficiale, lo strato algale costituito da piccoli grappoli di alghe unicellulari e un reticolo lasso di ife nella parte inferiore. Il peritecio maturo protrude verso l'esterno con la parte apicale in cui si apre l'ostiolo.

parte di Fry (1922), cui si rimanda per ulteriori dettagli.

In questi licheni il tallo, compreso lo strato algale, è completamente immerso nella roccia. In una sezione trasversale del tallo è visibile un addensamento delle ife nella parte superficiale della roccia, sotto al quale è localizzato lo strato algale. Al di sotto dello strato algale le ife si fanno più rade a costituire un reticolo lasso che corrisponde topologicamente alla medulla dei licheni crostosi epilitici. Nelle

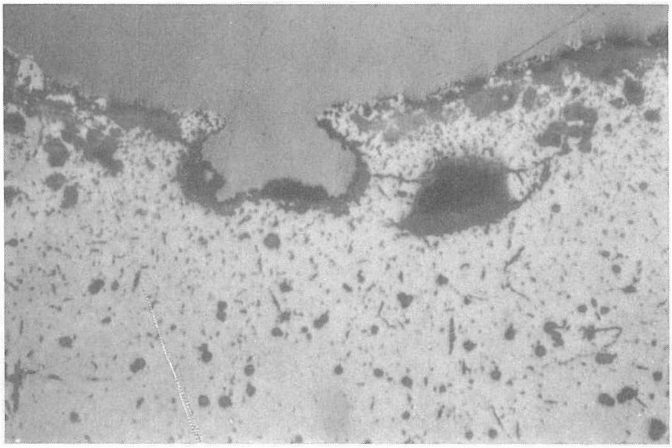


Foto 3 - Peritecio di *Baglietta parmigerella,* ingrandimento 400 X.
Fotografia al microscopio metallografico di tallo lichenico provvisto di substrato.
Ben visibili lo strato algale in prossimità della superficie della roccia, un peritecio in formazione all'interno della roccia e la cavità lasciata da un peritecio sulla superficie litica.

parti dei talli in cui la crescita è più intensa, e cioè al margine e nella porzione più profonda, appaiono numerose ife a cellule rigonfie, e piene di una sostanza oleosa. Secondo Fry (1922) questa sarebbe un prodotto di rifiuto formatosi in condizioni di basso tenore di azoto, forti concentrazioni di carbonato di calcio e di anidride carbonica derivante dagli intensi processi di respirazione legati alla crescita.

Il grado di penetrazione in profondità dipende dalla specie del lichene, dall'età del tallo e dal tipo di substrato. Secondo Smith (1921) le rizine di alcuni licheni calcicoli epilitici possono penetrare nella roccia sino a 15 mm di profondità, mentre Syers (1964) riporta uno spettro di penetrazione, basato sullo studio di più specie, che va da 0.3 a 16 mm.

I corpi fruttiferi del fungo (periteci) si originano anch'essi all'interno della roccia (Fig. 1; Fig. 2), da cui protrudono, a maturità, per la parte apicale. Essi formano quindi un incavo che, alla caduta del corpo fruttifero, appare come una profonda depressione (Fig. 3). La cavità può essere rapidamente occupata da uno strato pseudocorticale e gonidiale (Fry, 1922), oppure dalla ricristallizzazione di carbonato di calcio proveniente dalle acque dilavanti.

La superficie dei talli endolitici presenta una caratteristica micromorfologia: da un lato essa appare crivellata dalle depressioni prodotte dai periteci (Fig. 4), dall'altro, nelle zone di contatto tra diversi talli, appartenenti alla stessa o a più specie, è a volte evidente una rete di piccoli solchi che separano le porzioni centrali, sollevate, dei talli (Fig. 5). In casi estremi questo reticolo fa assumere alla superficie della roccia un caratteristico aspetto a ''mosaico''. Non è ancora chiaro quali siano le cause che determinano la formazione della struttura a mosaico. Un'i-

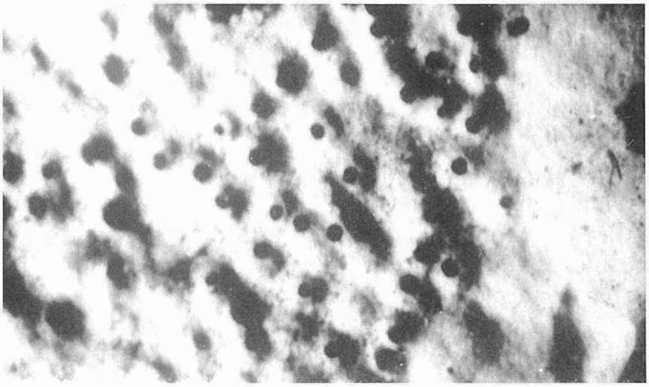


Foto 4 - *Bagliettoa parmigera*, ingrandimento 25 X.
Depressioni prodotte da periteci sulla superficie litica.

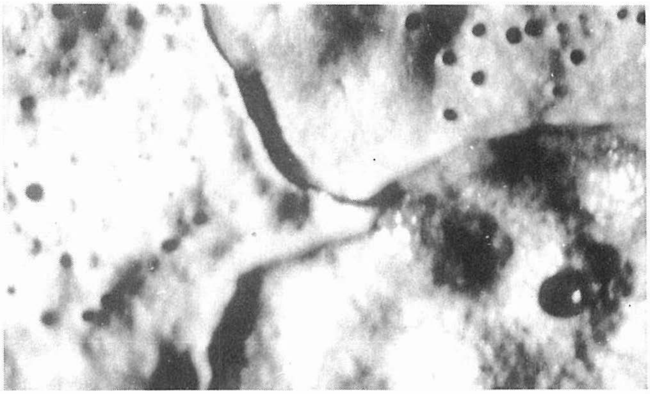


Foto 5 - *Bagliettoa parmigera:* mosaico di talli endolitici, ingrandimento 25 X. Microsolchi, spesso soggetti a fenomeni di microcarsismo, nelle zone di contatto tra talli diversi.

potesi, da sottoporre a verifica, sarebbe che nelle parti periferiche dei talli, dove lo strato gonidiale è assente e lo strato pseudocorticale molto sottile, si impostino dei fenomeni di microcarsismo tendenti alla dissoluzione della roccia; si formerebbe quindi un microreticolo idrografico, tendente ad approfondirsi; le parti centrali del tallo, protette dal tessuto pseudocorticale e dallo strato gonidiale, sarebbero invece meno soggette a fenomeni di microcarsismo, e questo spiegherebbe il fatto che esse appaiono rilevate rispetto alle parti marginali. Se questa ipotesi si rivelasse corretta, essa confermerebbe le affermazioni di Smith (1962) e di Lallemant & Deruelle (1978) secondo cui alcuni licheni eserciterebbero addirittura una funzione di protezione contro gli agenti fisico-chimici delle superfici litiche sottostanti.

Meccanismi di alterazione delle rocce carbonatiche

L'insediamento di organismi su materiale lapideo avviene solo dopo che questo ha già subito un processo di alterazione dovuto all'esposizione agli agenti atmosferici. La fenomenologia di attacco e i meccanismi di alterazione sono funzione del tipo di substrato, delle condizioni ambientali in cui il manufatto si trova e dello stato di conservazione delle sue superfici. I licheni che si insediano sulle superfici molto porose o comunque già deteriorate esercitano un'azione dannosa sia di tipo meccanico che di tipo chimico, ed è evidente che simili fenomeni degenerativi sono particolarmente distruttivi se il substrato è rappresentato da monumenti.

L'azione aggressiva di tipo meccanico è dovuta a due fattori: la penetrazione delle ife fungine nelle microfratture della roccia e le espansioni e contrazioni del tallo corrispondenti a diversi stati di idratazione (Lindsay, 1856; Smith, 1921; Fry, 1922, 1924, 1927; Perez-Llano, 1944; Levin, 1949). In questo modo sulle pareti delle fessure si creano degli sforzi tensoriali che inducono lo sfaldamento delle superfici litiche. È probabile che l'alterazione meccanica prodotta dai licheni non sia successiva all'alterazione biochimica, ma piuttosto si tratti di una fase preliminare in quanto le ife che si introducono nelle fessure della roccia e vi si concentrano possono rilasciare soluzioni chimiche corrosive (Fry, 1924).

L'alterazione chimica invece è molto più grave di quella meccanica perché le sostanze rilasciate dalle ife sono responsabili della solubilizzazione, per una profondità di qualche millimetro, dei minerali che costituiscono il substrato. Questa azione solubilizzatrice provoca un aumento della porosità della roccia e quindi l'esposizione ad altri agenti inquinanti di superfici più ampie.

I principali responsabili dell'aggressione chimica sembrano essere gli acidi lichenici, l'anidride carbonica e l'acido ossalico.

Gli acidi lichenici sono sostanze scarsamente solubili in acqua, riconosciuti come agenti chelanti. La reazione di queste sostanze con i minerali inclusi nella roccia e la formazione di complessi insolubili (Iskandar & Syers, 1971), non sembra però essere particolarmente importante nella dissoluzione del calcare (William & Rudolph, 1974).

L'anidride carbonica derivante dalla respirazione è parzialmente responsabile della alterazione della roccia nelle vicinanze del lichene (Fry, 1922). Il biossido di carbonio si scioglie in acqua e viene trattenuto nelle fessure e nei pori della roccia. La presenza di acido carbonico determina una maggior solubilità del calcare e la formazione di bicarbonati solubili che possono essere dilavati, o ricristalizzare nuovamente in carbonato di calcio e formare delle incrostazioni.

La grande quantità di cristalli di ossalati osservati attorno alle ife e sui talli di licheni sassicoli (Smith, 1921), fece pensare che il lichene producesse l'acido ossalico. In effetti è stato dimostrato che è il fungo a produrre l'acido ossalico (Syers & Iskandar, 1973; Jones et al. 1980; Wilson et al. 1981) in quanto la dissoluzione della roccia osservata sulla superficie di contatto con il tallo lichenico è analoga a quella che si ottiene simulando un aggressione in vitro delle rocce con acido os-

salico (Ascaso et al., 1982).

Misure di intervento

I risultati poco soddisfacenti ottenuti da Giacobini et al. (1979, 1987) nel trattamento di superfici litiche attaccate da licheni endolitici con biocidi derivano probabilmente dal fatto che la maggior parte dei talli lichenici è costituita da ife fungine a parete composta da una sostanza chitinosimile. La chitina, un composto generalmente raro nel regno vegetale, molto più frequente in quello animale (è il principale costituente dell'esoscheletro degli artropodi), viene decomposta molto difficilmente. Uno dei pochi organismi in grado di decomporre la chitina è il *Bacillus chitinosus*, un batterio che vive di norma nel suolo. L'applicazione di biocidi determina la morte delle alghe simbionti e generalmente anche delle cellule fungine. Nei licheni crostosi epilitici ciò si traduce in una perdita di consistenza del tallo, che inizia a frammentarsi e a volte anche a staccarsi dal substrato per cause fisiche. Un trattamento di questo tipo, in tale caso, può soltanto facilitare l'asporto meccanico dei talli lichenici. Tuttavia, quest'ultimo non presenta di norma particolari difficoltà nel caso di licheni epilitici. A nostro parere, un pretrattamento con biocidi sarebbe consigliabile soltanto nel caso si volessero asportare licheni epilitici riproducentisi per via vegetativa: in tale modo verrebbe eliminata una grande quantità di propaguli (soredi od isidi), il che potrebbe costituire un intervento di tipo preventivo contro la ricolonizzazione del substrato (Nimis et al., 1987). Nel caso di licheni nitrofili, che hanno crescita piuttosto rapida, sarebbe anche importante associare all'azione distruttiva degli interventi preventivi, atti ad abolire le cause dell'eutrofizzazione.

Nel caso invece dei licheni endolitici, il trattamento con biocidi, pur determinando la morte di alghe e funghi, non si traduce in risultati evidenti a breve termine in quanto le ife fungine, di difficile decomposizione, permangono lungamente nella roccia. La morte e decomposizione delle cellule algali determina la formazione di uno strato permeabile all'acqua al di sotto della porzione pseudocorticale, che comunque si mantiene a lungo in quanto costituita da ife fungine. La degenerazione del tallo lichenico procede con la desquamazione dello strato pseudocorticale, che si stacca a piccole scaglie, lasciando libera una superficie a struttura spugnosa sottostante a quello che era lo strato gonidiale. Il risultato è che un tale tipo di intervento determina l'esposizione di una superficie litica molto più soggetta all'attacco da parte di agenti atmosferici (fenomeni di microcarsismo, assorbimento di inquinanti etc.) di quanto non avvenisse in presenza di un tallo lichenico vivo. La velocità di questi processi non è nota, ma è presumibile che sia piuttosto lenta. A Lucus Feroniae, nei dintorni di Roma, abbiamo osservato la desquamazione di talli endolitici morti crescenti su colonne che erano state a lungo interrate. La composizione chimica delle sottili scaglie mostrava una forte concentrazione di ossalati. L'aspetto macroscopico e le caratteristiche fisiche delle scaglie stesse ricordavano fortemente le patine riscontrate su diversi manufatti di epoca romana, quali ad esempio la Colonna Traiana. Non è da escludere che tali pa-

tine siano, almeno in parte, anche di origine biologica, e rappresentino vecchi talli di licheni endolitici in via di desquamazione, anche tenendo conto del fatto che molti manufatti litici dei Fori Romani sono a tutt'oggi ricoperti, almeno alla base, da specie endolitiche. Questa ipotesi andrebbe comunque verificata con uno a studio ad hoc.

Conclusioni

Dalle considerazioni esposte sopra si può concludere che il trattamento di superfici litiche attaccate da licheni endolitici a scopo restaurativo/conservativo risulta particolarmente difficile, e sconsigliabile nella maggior parte dei casi. Un trattamento con biocidi determina l'esposizione di una superficie porosa, facilmente aggredibile da agenti fisico-chimici o biologici. L'asporto meccanico, per la natura stessa dei talli endolitici, comporta inevitabilmente l'abrasione di uno strato superficiale di spessore variabile.

In particolare, nel trattamento chimico o meccanico di manufatti parzialmente ricoperti da licheni epilitici, si dovrà prestare la massima attenzione alla presenza, su parti del manufatto, di eventuali forme endolitiche, per evitare effetti collaterali non desiderati.

Fortunatamente, le forme licheniche calcicole a tallo endolitico non determinano, in generale, una forte alterazione cromatica della roccia, e quindi il loro asporto andrebbe limitato soltanto ad alcuni casi altamente specifici.

Riassunto. I licheni endolitici comprendono sia forme pirenocarpe che forme discocarpe; le prime sono molto più frequenti su substrato calcareo. Nei licheni endolitici calcicoli il tallo si trova completamente infossato all'interno della roccia, ed è costituito da uno strato pseudocorticale superficiale, da uno strato gonidiale contenente le alghe, e da uno strato, ad esso sottostante, formato da ife a tessitura lassa. La formazione dei corpi fruttiferi, che sono parzialmente o totalmente immersi nella roccia, determina fenomeni di ''pitting'', particolarmente evidenti in talune specie. Gli interventi di asporto dei licheni endolitici calcicoli a scopo restaurativo-conservativo sono particolarmente difficili. Il motivo principale è dato dal fatto che la decomposizione delle ife fungine è molto più lenta di quella delle cellule algali: si determina quindi la formazione di uno spazio vuoto, un tempo occupato dallo strato gonidiale, disposto sotto la parte pseudocorticale morta e non ancora decomposta. Tale spazio può venir invaso dall'acqua, e ciò può determinare, soprattutto nei mesi più freddi, la desquamazione dello strato superficiale. In questo modo viene esposta all'aria una superficie fortemente porosa, che si presta facilmente ad attacchi da parte degli agenti atmosferici o di sostanze inquinanti.

Bibliografia

Ascaso C., Galvan J. & C. Rodriguez Pascual, 1982. *The weathering of calcareous rocks by lichens.* Pedobiologia 24: 219-229.

Fry E.J., 1922. *Some types of endolithic lichens.* Ann. Bot. London 36: 541-562.

Fry E.J., 1924. *A suggested explanation of the mechanical action of lithophytic lichens on rocks (shale).* Ann. Bot. London 38: 175-196.

Fry E.J., 1927. *The mechanical action of crustaceous lichens on substrata of shale, schist, gneiss, limestone and obsidian.* Ann. Bot. London 41: 437-460.

Giacobini C., Bettini C. & A. Villa, 1979. *Il controllo dei licheni, alghe e muschi.* 3° Congr. Int. Deterioramento e Conservazione della Pietra, Venezia: 305-312.

Iskandar I.K. & I.K, Syers, 1971. *Solubility of lichen compounds in water: pedogenetic implications.* Lichenologist 5: 45-50.

Lallermant R. & S. Deruelle, 1978. *Présence des lichens sur les monuments en pierre:nuisance ou protection?* UNESCO-Rilem, Internat. Symp. on Deterioration and Protection of Stone Monuments, Paris.

Levin F.M., 1949. *The role of lichens in the weathering of limestone and diorites.* Vertin., Mosk., Gos,. Univ.9: 149-159.

Lindsay W.L., 1856. *A popular history of British lichens.* Lovell Ree, London.

Jones D., Wilson M.J. & M.J. Tait, 1980. *Weathering of a basalt by Pertusaria corallina.* Lichenologist 12: 277-289.

Nimis P.L., Monte M. & M. Tretiach, 1987. *Flora e vegetazione lichenica di aree archeologiche del Lazio.* Studia Geobotanica, 7: 3-161.

Perez-Llano G.A., 1944. *Lichens: their biological and economical significance.* Botanical Review 10: 2-65.

Smith A.L., 1921. *Lichens.* Cambridge Univ. Press. London and New York.

Syers J.K., 1964. *A study of soil formation on carboniferous limestone with particular reference to lichens as pedogenetic agents.* Ph. D. Thesis. University of Durham. England.

Syers J.K. & I.K. Iskandar, 1973. *Pedogenetic significance of lichens.* The Lichens (Ahmadjian V. & M.E. Hale) 225-248- Academic Press, New York.

Williams M.E. & Rudolph, 1974. *The role of lichens and associated fungi in the chemical weathering of rock.* Micologia, 66: 648-660.

Wilson M.J. & W.J. Mc Hardy, 1981. *The weathering of Serpentinite by Lecanora atra.* Lichenologist, 18: 167-176.

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